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Fabrication of J79 Boron/Aluminum Compressor Blades

Final Report

by

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16. Abstract

Eighty-one (81) J79 Boron/Aluminum first-stage compressor blades were fabricated under this NASA program. They were then processed further and tested under Air Force contract F33657-76-C-0608. Seventy-three (73) blades were fabricated by General Electric and 8 blades were fabricated by TRW.

This report describes the processing of the blades and the series designations established for the various types of tests the blades were to undergo under the Air Force program.

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SUMMARY

A total of 81 J79 B/Al first-stage compressor blades was fabricated in this program and transferred to the Air Force program, F33657-76-C-0608, for further processing and testing. These were composed of 73 blades fabricated by GE and 8 blades fabricated by TRW.

The TRW blades were designated W series while the GE blades were divided into four series designations: X, S, T, and L. The blades were transferred to the Air Force program in four installments:

(1) X and W series for an experimental screening test.

(2) S series for a sensitivity test.

(3) T series for a full-stage impact test.

(4) L series for L-quality blades for possible ground engine testing.

1.0 INTRODUCTION

This report documents the work accomplished during the fabrication of the J79 boron/aluminum composite Stage 1 compressor blades in the NASA Program, NAS3-18943. The objective of the program was to fabricate J79 boron/aluminum compressor blades for application to various J79 test programs conducted under Air Force Contract F33657-76-C-0608. The technical effort was carried out in Task I, Blade Fabrication. The Task II effort consisted of reporting program progress.

1.1 BACKGROUND

For the past five years, impact-resistant blades have been extensively developed in programs such as the "Boron/Aluminum Impact Improvement Program" (Air Force Contract AF33615-74-C-2066) and "B/Al Fan Blades for SCAR Engines Program" (NAS3-18910), as well as in General Electric internally funded programs. A number of these blades demonstrated resistance to foreign object damage (FOD). This success appeared to result from the use of an 1100-aluminum matrix along with the development of improved blade fabrication procedures and processes.

To evaluate the material/process parameters and two separate processors, two programs were closely coordinated. This NASA Program, "J79 Boron/Aluminum Composite Compressor Blades" (NAS3-18943), funded the fabrication of J79 B/Al blades needed for the evaluation. Once fabricated, the blades were transferred to the Air Force Program, "J79 Boron/Aluminum Blade Design, Fabrication, and Test" (F33657-76-C-0608), for test preparation and actual testing.

1.2 SCOPE

From two fabricators, TRW, Inc. (TRW) and General Electric Company (GE), six combinations or designs were selected for evaluation. These consisted of three combinations (design types) of materials, involving different aluminum alloys for the matrices and various orientations of the 0.142 mm (0.0056 inch) diameter boron filaments. Two of the design types were each supplied by both fabricators; these comprise Designs A, B, D, and E. In addition, GE alone provided two additional designs, C and F. The designs and the fabricators are tabulated in Table I.

Table I. J79 B/Al Blade Designs and Fabricators.

Design Designation	Design Type	Fabricator
A	All-1100	General Electric
B	Bimetal	General Electric
C	ATAC	General Electric
D	All-1100	TRW
E	Bimetal	TRW
F	Modified Bimetal	General Electric

To document the blade fabrication, this report covers three subjects:

1. Number designation system
2. Fabrication process
3. Blade description

The number designation system explains in detail the genetic record of each blade. Since the processes used by TRW are proprietary to that firm, only the General Electric fabrication process is presented in the fabrication process section. The procured lot of blades fabricated by TRW is documented in the blade description section, together with the series of blades fabricated by General Electric.

2.0 BORON/ALUMINUM J79 BLADE FABRICATION

The blades fabricated in this program were needed to evaluate the effects of three B/Al material design types, from two blade fabricators, on blade starling-impact resistance.

The basic process developed for blade fabrication was developed prior to this program and was reported in Reference 1. The GE blade fabrication process is reported herein in its current form. For continuity and completeness, much material from Reference 1 is included.

Section 2.1 explains the blade number designation system. Section 2.2 details the fabrication process.

2.1 NUMBER DESIGNATION SYSTEM

To provide a genetic record of each blade within its serial number, a numerical designation system was developed as an integral part of the boron/aluminum (B/Al) blade fabrication program. The system aids in keeping track of six design variations through four series of J79 blades. Four of these design variations were fabricated by GE, the other two by TRW.

To keep track of the various designs, materials, series, fabricators, serial numbers, etc., each series had a basic designation of CJ79-556 (or TJ79-556) that is followed by letters and numbers designating the blade matrix material, the series, and the serial number, in that order. In the basic designation,

CJ79- * * *

C distinguishes the blade from earlier design efforts; to designate a TRW fabricated blade, C is replaced by T.

J79 identifies the blade as a J79 engine blade.

The next four symbols tell blade characteristics. For instance: for Design A, designated

CJ79-5561-* * *,

the initial 5 denotes a volume fraction of 50 v/o for a ±15° filament arrangement,

the 56 denotes that the boron filaments are 0.142 mm (0.0056 in.) in diameter.

the 1 denotes that the matrix is of 1100 Al alloy,

That last symbol is modified when it is to designate a design whose matrix uses a different arrangement. For instance: in the code for Design C, which is represented as

CJ79-5562/1-* * *,

the 2/1 denotes an ATAC-design blade. The acronym ATAC stands for Alternating Two Aluminum Composite in which matrix materials of 2024 Al and 1100 Al are alternately arranged on each monotape throughout the thickness of the blade.

Design B, with its bimetal matrix material system, serves as a second example of an alternative matrix arrangement. It is coded:

CJ79-556(2/1R-1T)-* * *.

The 2/1R tells us that an ATAC system is used in the root.

The 1T denotes that an 1100 Al matrix is used in the tip.

A complete designation example, representing a blade of Design B, runs as follows:

CJ79-556(2/1R-1T)-1T12

Regarding the last four symbols:

The 1 denotes that this particular bimetal design type is Design B. Design F would be denoted by a 2. No digit precedes an X or a W, for every bimetal-version blade in these series is of Design B.

The T stands for Series T, as distinguished from X, W, S, and L.

The unique number for this blade is 12; for some blades this will be a single digit.

Each blade was marked with its complete serial number, but for quick identification a shorter number was needed. In day-to-day activity, therefore, only the series letter and the one- or two-digit individual blade number were used. These abbreviated versions appear frequently in this report.

2.2 FABRICATION PROCESS

The steps required for the fabrication of the J79 B/Al blades are outlined in Figure 1. These steps resulted in consolidated blades that were transferred to Air Force Contract F33657-76-C-0608 for use in various J79 test programs. These process operations were developed using earlier process refinements and a knowledge of the requirements for the manufacture of aircraft engine blades.

2.2.1 Incoming Material

As an integral part of the blade fabrication sequence, each operation had a check point. The incoming material was ordered in accordance with the specifications shown in Table II.

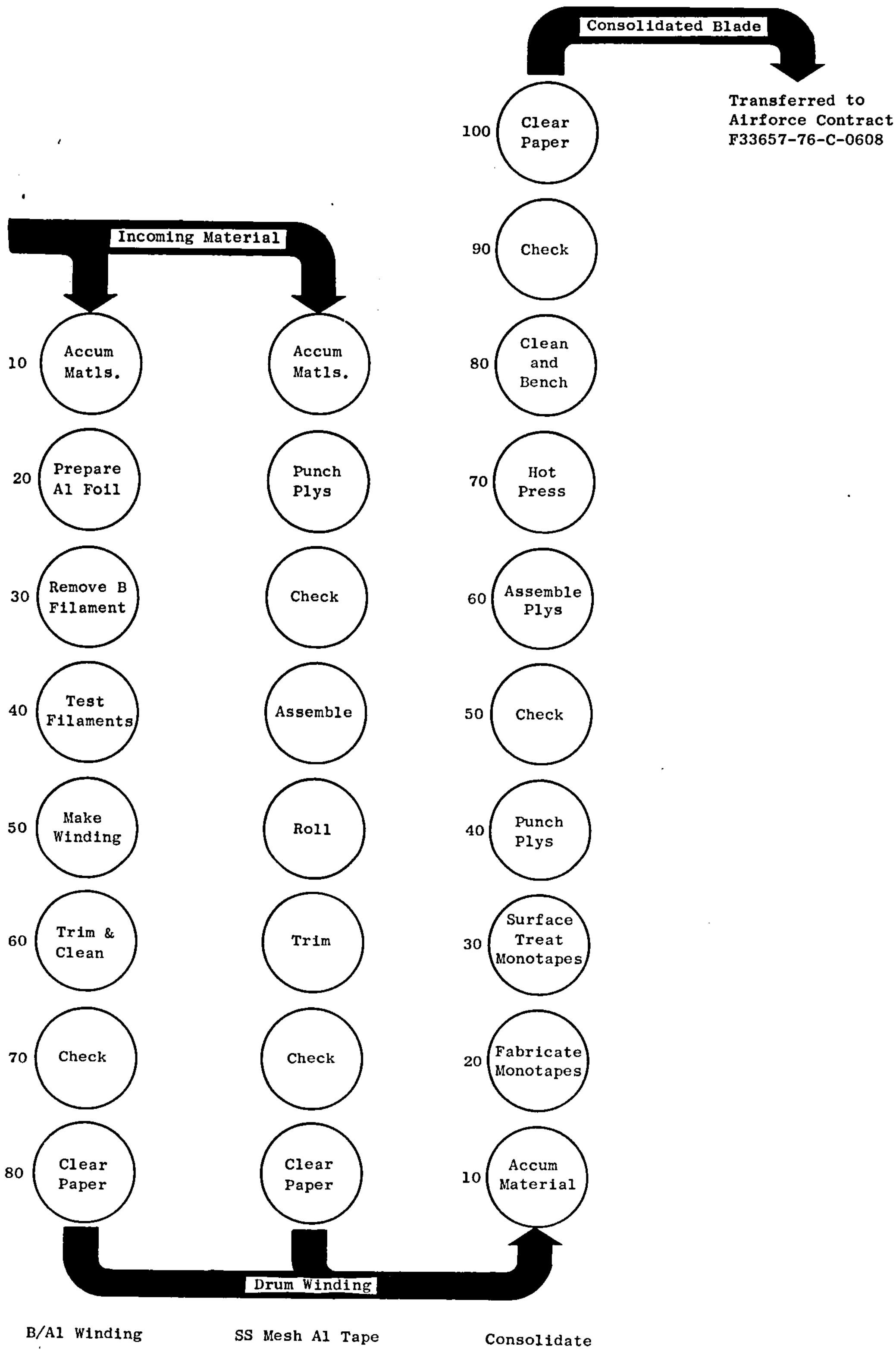


Figure 1. Flow Diagram for Fabrication of J79 B/Al Blades.

Table II. Incoming Materials Specifications.

Material	Specification
Boron Filament	4013155-588 (Class A)
2024 Aluminum Alloy Foil	QQ-A-250/4D
1100 Aluminum Alloy	QQ-A-250/1
316 Stainless Steel Wire Cloth (150 Mesh)	RR-W-36A Type I
Polystyrene Cement	---

Each incoming raw material, when received, was assigned a quality assurance (QA) number. In addition, the material description, the date, the purchase order number, and the item number, along with the receiver number, were listed in a QA log book. Then the material would be prominently tagged or marked with the material description and QA number.

A sample each of the received aluminum alloys, stainless steel, and polystyrene was then sent to the Analytical Chemistry Lab for analysis. The aluminum alloys were analyzed for compliance with the chemical composition limits shown in Table III.

Table III. Chemical Composition Limits for the Aluminum Alloy.

Element	2024 Al Alloy Composition Limits (%)	1100 Al Alloy Composition Limits (%)
Cu	3.8 to 4.9	0.05 to 0.2
Mg	1.2 to 1.8	0.05 Max
Mn	0.3 to 0.9	---
Si	less than 0.5	1.0 Max (Si + Fe)
Fe	less than 0.5	
Cr	less than 0.1	---
Zn	less than 0.25	0.1 Max

A sample larger than 150 mm x 150 mm (6 in. x 6 in.) pulled from a lot of received stainless steel mesh material was analyzed for conformance to the chemical element percentages shown in Table IV.

Table IV. Chemical Composition Limits for AISI 316 Stainless Steel

Example	Composition Limits (%)
Cr	16 to 18
Ni	10 to 14
Mo	2 to 3

The 25-gram (0.88-ounce) sample of the polystyrene cement was scanned by infrared. The scan trace was examined and matched to the standard set traces for the polystyrene cement.

The boron filament strengths were determined and the data recorded in accordance with the procedure outlined in the Boron/Aluminum Winding Operation Sheet. Details of these results are recorded in the following subsection, Drum Winding. Any material found unacceptable was red-lined (a red, felt-tipped marker drawn through the QA number) and either scrapped or returned to the vendor for replacement, credit, or both.

2.2.2 Drum Winding - B/Al Tape

The tapes were prepared by drum-winding 0.142 mm (0.0056 in.) diameter boron filament onto an 1100 Al alloy backing foil, using the drum winding equipment shown in Figure 2.

The 1100 Al foil was then wrapped tightly around the drum with a tensioning device and its outer surface roughened with a nylon abrasive pad (3M surface treatment) until the gloss was gone. With the drum rotating, the foil was then cleaned with acetone and sprayed with polystyrene cement. The boron filament wire was then fed into the in-line cleaning station (shown in Figure 3) which contained a tricloroethane-saturated sponge on the aft end of the wire guide.

Before winding the boron filament, five 0.735-meter (30-inch) lengths cut from the beginning were tensile tested with 2.54 cm (1.0 inch) gage length. Table V records the winding numbers and the blades the windings were used on on, plus the boron filaments diameters, strengths, standard deviations, and coefficients of variation. The strengths were found to be within the specifications.

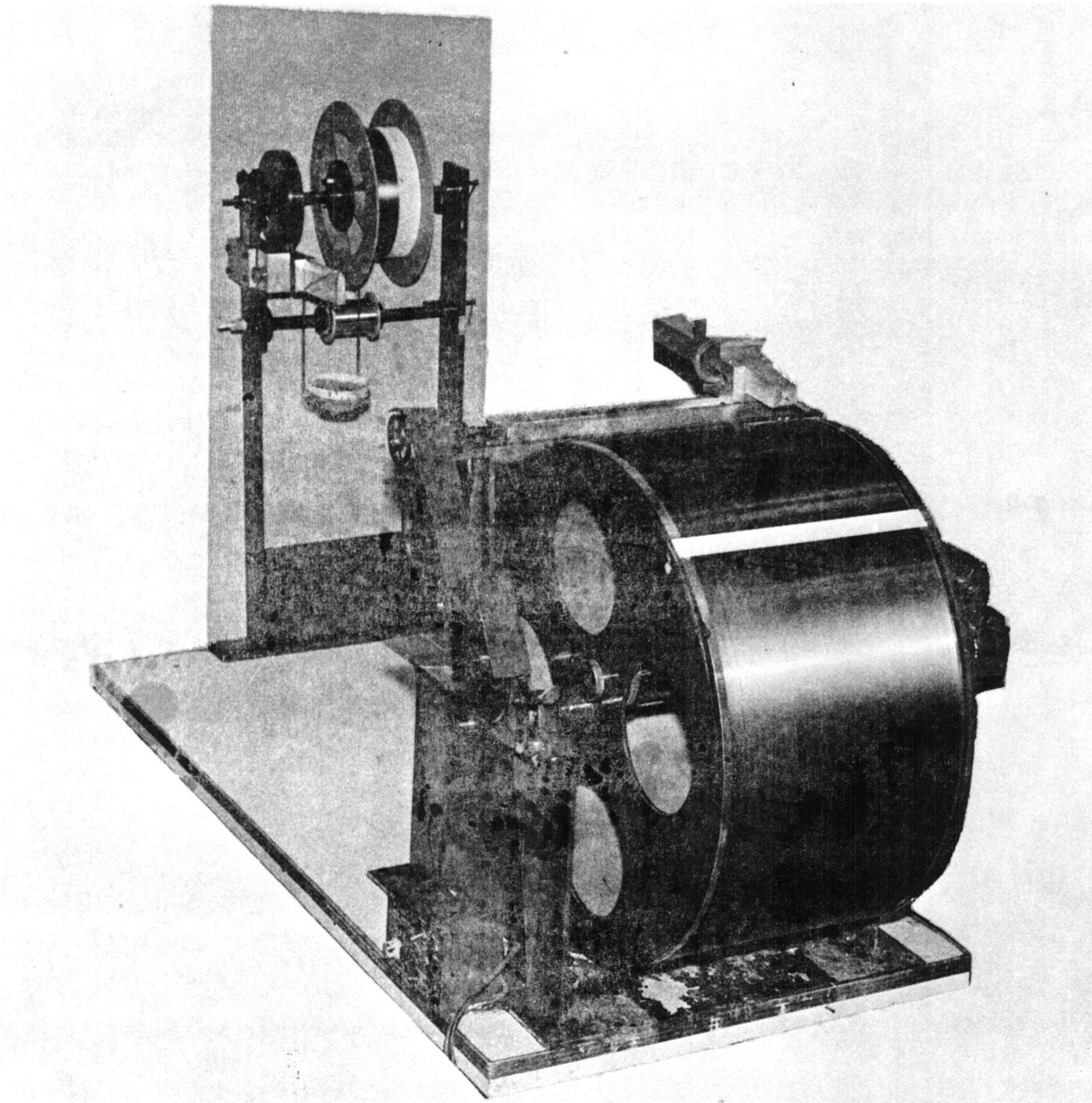


Figure 2. Drum Winding Equipment with a Completed Winding on the Drum.

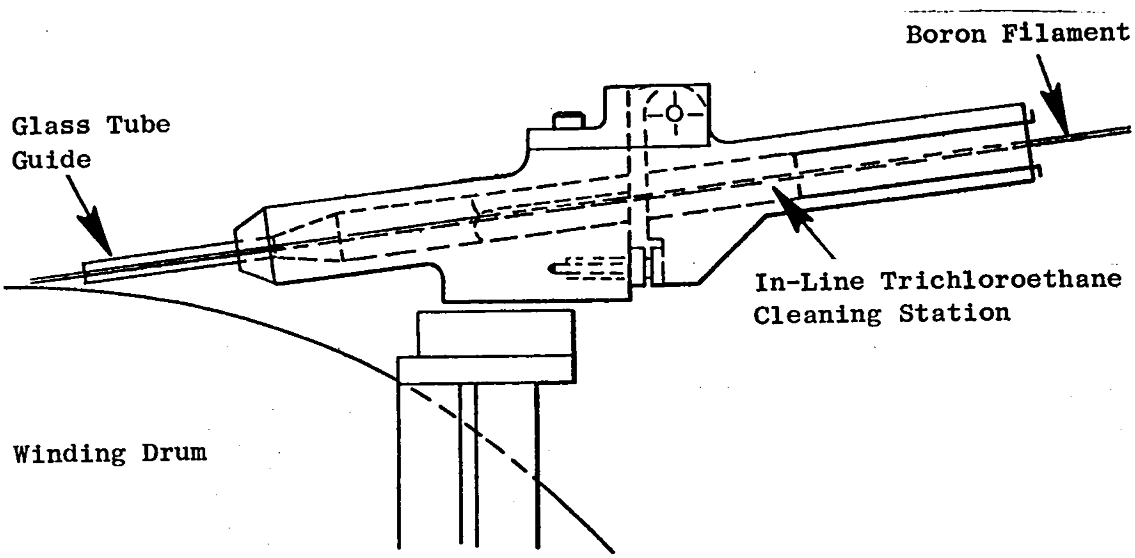


Figure 3. Schematic of the Wire Guide Assembly Used in Preparing the B/Al Tape.

Table V. Tensile Strengths of Boron Filaments Prior to Winding.

- Gage Length: 2.54 cm (1.0 inch)

Winding Number	Blade S/N	Diameter (0.001 inch)	Average Strength (ksi)
C16(6.5)-66	IT1	5.50	500
-64	2	5.57	476
-64	3	5.57	476
-90	4	5.66	465
-99	5	5.48	500
-94	6	5.50	471
-93	7	5.40	463
-93	8	5.40	463
-102	9	5.51	460
-101	10	5.50	456
-122	11	5.50	573
-133	12	5.40	523
-137	13	5.60	459
-137	14	5.60	459
-134	15	5.50	527
-117	16	5.52	559
-113	17	5.61	497
-128	18	5.54	481
-127	19	5.54	469
-132	20	5.53	470
-125	21	5.50	459
-131	22	5.48	475
-134	23	5.50	527
-143	24	5.49	563
-144	25	5.52	451
-148	26	5.57	545
-150	27	5.53	491
-150	28	5.53	491
-146	29	5.59	552
-146	30	5.59	552
-155	31	5.47	595
-155	32	5.47	595
-160	33	5.69	565
-156	34	5.41	560
-164	35	5.56	506
-160	36	5.69	565

Table V. Tensile Strengths of Boron Filaments Prior to Winding (Concluded).

- Gage Length: 2.54 cm (1.0 inch)

Winding Number	Blade S/N	Diameter (0.001 inch)	Average Strength (Ksi)
C16(615)-165	L001	5.57	487
-165	002	5.57	487
-168	003	5.63	467
-168	004	5.63	467
-174	005	5.55	504
-170	006	5.60	459
-180	007	5.49	451
C16(6.5)-172	L008	5.61	469
-187	009	5.65	581
-182	010	5.51	484
-178	011	5.67	473
-182	012	5.51	484
-186	013	5.56	489
-186	014	5.56	489
-190	015	5.41	506
C16(6.5)-193	1L001	5.48	466
-202	002	5.60	491
-196	003	5.50	497
-196	004	5.50	497
-199	005	5.40	602
-194	006	5.46	534
-207	007	5.57	491
-211	008	5.40	484
-208	009	5.61	510
-208	010	5.61	510
-214	011	5.43	534
-216	012	5.46	491
-212	013	5.45	532
-219	014	5.40	467
-220	015	5.40	554
-239	016	5.41	462
-239	017	5.41	462

Winding was initiated by positioning the wire guide about 6.4 mm (1/4 inch) from the edge of the aluminum foil. The guide movement was checked to assure a displacement of 0.1592 mm (0.0065 inch) per revolution of the drum. The boron filament was wound at a speed selected to minimize crossovers and gaps. After the winding reached 0.305 meter (12 inches) in width, the drum was stopped. During this winding process additional polystyrene cement was periodically added by means of an aerosol spray.

The completed winding then was cut from the drum, placed on a clean flat table, and thoroughly checked for gaps, laps, and filament crossovers. Each winding number was recorded on one of the tape ends, and all of the data records were reviewed and approved.

2.2.3 Bonded Monotape

Bonded monotapes, 0.196 mm (0.007 inch) thick, were the next to be fabricated. This was done by hot-pressing monotape preforms. A brief description of each step in the process cycle for monotape fabrication is given schematically in Figure 4 and described below. A more complete record of the PROS (Protective Reproducible Outer Sacrificial) sheet process development is presented in Reference 2.

The tape windings were cut to dimensions of 216 mm by 381 mm (8-1/2 inches by 15 inches), and the boron fibers were covered with an aluminum foil cover sheet to make up a monotape preform. During this program, three types of cover sheets were used. Depending on the type of monotape fabricated, they were either:

- 1100 Al alloy foil.
- 2024 Al alloy foil.
- A combination of 1100 and 2024 Al alloy foil, each covering half the length of the monotape.

Prior to placement of the cover sheet, both the 1100 and the 2024 Al foils were abraded with the 3M surface treatment, cleaned with acetone, and spray coated with polystyrene cement.

Next, the monotape preforms were hot-pressed using the protective reproducible outer sacrificial (PROS) sheet process.

The PROS sheet was of 1100-H18 aluminum foil, 0.0762 mm (0.003 inch) thick. After being cleaned with acetone, it was surface treated by being dipped into an Alodine solution for 20 to 30 seconds, rinsed with water, and air dried. The PROS sheet was then placed on the outer surface of each B/Al monotape preform.

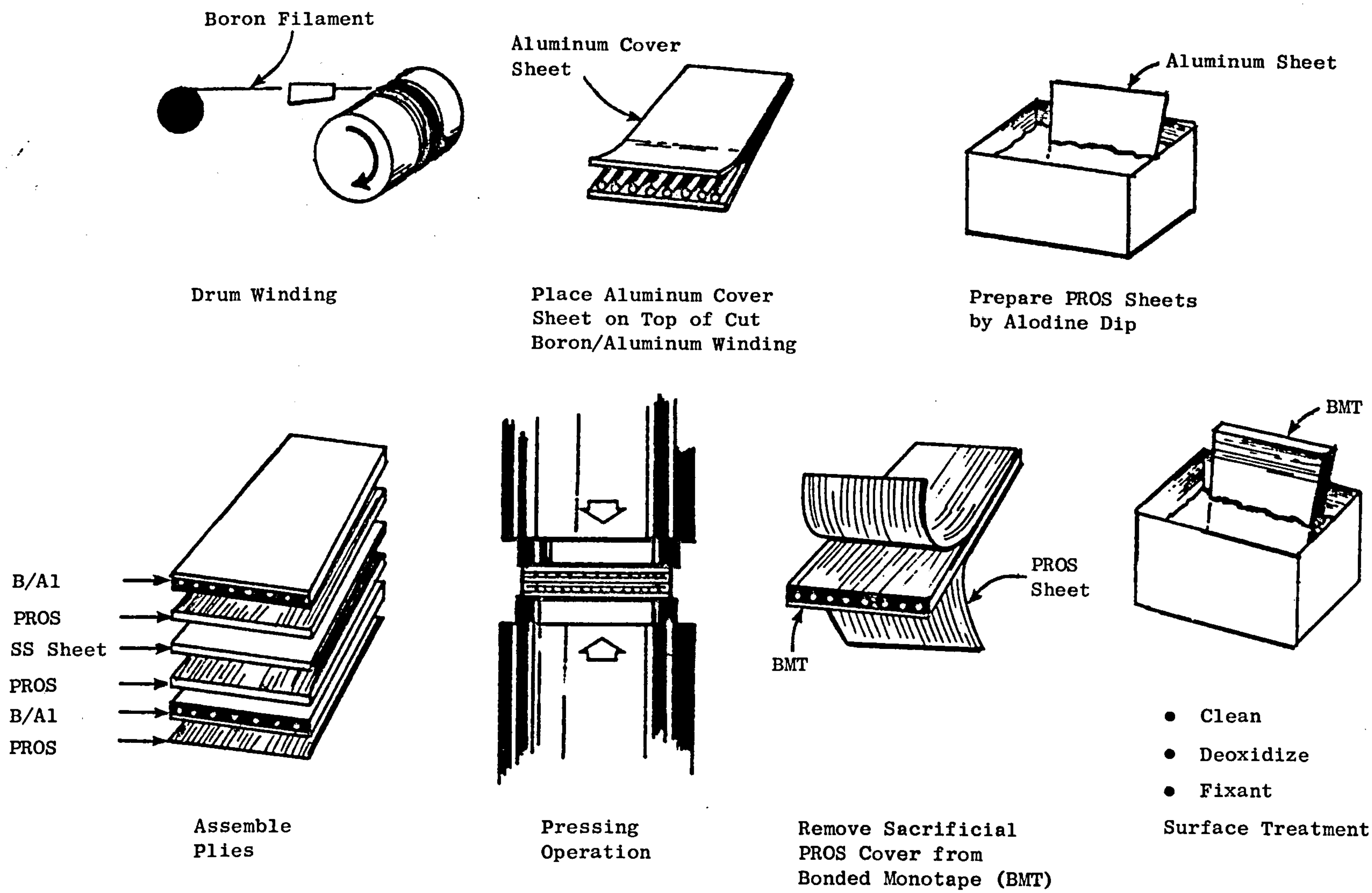


Figure 4. Schematic of Preparation of B/Al Bonded Monotapes by the PROS (Protective Reproducible Outer Sacrificial) Sheet Process.

For the pressing operation, a 0.127 mm (0.005 inch) thick stainless steel sheet was placed on the outer surface of the PROS sheet. The stackup sequence for pressing several B/Al monotapes was as follows: stainless steel sheet, PROS sheet, B/Al monotape preform, PROS sheet, stainless steel sheet, PROS sheet, B/Al monotape preform, PROS sheet, stainless steel sheet, etc.

The stackup of monotapes was placed at room temperature in a Williams and White vacuum hot press between 25 mm (1 inch) thick plates measuring 281 mm by 305 mm (12 inches by 15 inches). The chamber was evacuated, and the temperature was slowly increased to 390° C (735° F). After a complete outgassing of the polystyrene binder, the temperature was increased to about 468° C (875° F), and pressing continued at a pressure of 24.1 MPa (3.5 ksi) for 10 minutes. The stackup of monotapes was then allowed to cool to room temperature under a vacuum atmosphere. At room temperature the pressing load was released, and the chamber was backfilled with argon gas. Next, the chamber was opened and the pressed monotapes removed. The stainless steel sheets were then removed from the ply stackup. Each monotape was sequentially marked with an identification number and stored for future use.

After hot-pressing, the PROS sheet was peeled off, and the four outer edges of the monotape were trimmed. The uncovered ends of the boron filaments were then sealed by dipping them into a liquid rubber sealer. This sealing prevented intraply contamination during the following surface treatment. As a final preparation of the monotapes, a Stillman/Farmer No. 9 surface treatment was applied to both sides of the monotape. The steps required for the treatment are recorded in Table VI.

Table VI. Stillman/Farmer No. 9 Surface Treatment.

Step	Surface Treatment	Chemical	Temperature ° C (° F)	Time, Sec	Rinse
1	Cleaner	Ridoline No. 72 1 oz/gal	60 (140)	30	H_2O
2	Deoxidizer	Deoxidizer No. 7 4 oz/gal with 10% HNO_3	24 (75)	120	H_2O
3	Fixant	Deoxylyte No. 11 1 ml/1600 ml H_2O	24 (75)	300	None

2.2.4 Stainless Steel Mesh/Aluminum Tape

The stainless steel (SS) mesh/Al plies were fabricated by sandwiching the 316-type stainless steel 150-mesh wire cloth between two 2024 Al alloy sheets. Two thicknesses of SS mesh/Al sandwich tape material were fabricated for J79 blade fabrication. The dovetail insert plies were formed from Al foils 0.038 mm (0.0015 inch) thick, and upon consolidation this sandwich assembly formed an individual ply 0.119 mm (0.0047 inch). The second type of SS mesh/Al, used as an 0.142 mm (0.0056 inch) thick outer covering (steel belted) on the blade, was formed by sandwiching the SS wire cloth between two 0.051 mm (0.002 inch) thick aluminum foils.

In the manufacture of these stainless steel/Al tapes, individual plies 89 mm by 292 mm (3-1/2 inches by 11-1/2 inches) were made for both tape thicknesses. The stainless steel mesh was cut to these dimensions; the 2024 Al foil was cut to twice the required length and folded to let the stainless steel mesh slip inside of it. The assembly was then placed between 0.0025 mm (0.001 inch) thick Mylar films cut to more than twice the stainless steel length and 5 cm (2 in.) wider than the assembly to ensure the complete encapsulation of the entire surface of the sandwiched stainless steel/Al assembly. These Mylar-jacketed preform assemblies were then rolled and the Mylar film removed from each tape.

The completed tape was finally trimmed; all the data records were reviewed and approved.

2.2.5 Ply Generation and Assembly

The ply patterns for the airfoils and dovetail regions were generated for the 0.119 mm (0.0047 inch) ply thickness on the Tridea Automatic Graphics System, shown in Figure 5, to an accuracy of ±0.001 mm overall thickness at 20-power magnification. These individually generated plies were then transferred to Mylar masters which were cut and stacked to determine the consistency of the contour surfaces. Inconsistencies were then rechecked, against the originally produced masters, and corrected. These corrected master-ply patterns served as a standard for producing Mylar copies. The copies were later used to hand-cut the B/Al and SS mesh/Al ply patterns or to produce clicker dies.

Since the clicker dies already existed from the earlier development program (AF33615-74-C-2066), no hand-cut plies were required until the bimetal-type blade was introduced. Plies for Designs A and C were all cut by clicker dies. For the early Design B blades used in the X series, a few plies were hand-cut. Even then, only a few plies had to be modified iteratively to produce acceptable Design B blades for the experimental screening test series.

Figure 5. TRIDEA Automatic Graphics System.

After each blade was consolidated the blade surfaces were scrutinized for uniformity of flow and filling. On regions that exhibited nonuniform pressure-marked surfaces, the ply patterns were modified to correct the irregularities. Upon completion of this stage of blade manufacture refinement, new Mylar master plies were made for the Design B blades.

After satisfactorily establishing the ply patterns, a complete set of steel-rule clicker dies for Design B was procured using a set of the Mylar master plies. All remaining Design B blades for the S, T, and L series were cut by these clicker dies. The ply orientation and laminate sequence of the blades produced in this program are shown in Figure 6.

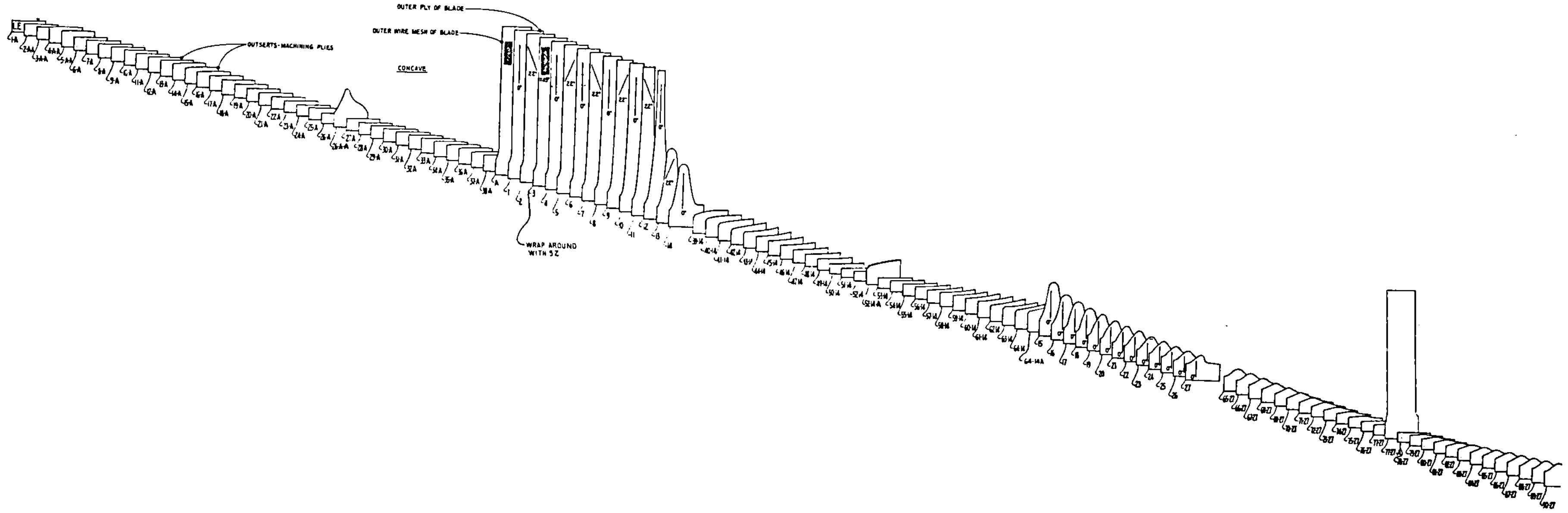
Typical clicker die patterns can be seen in the center of Figure 7. To the left is a drum winding section prior to punching-out the patterns which are seen on the right. Figure 8 shows the clicker press and a set of the steel rule dies used to stamp out the B/Al plies.

The stainless steel mesh/Al ply patterns were generated, and steel rule clicker dies were formed. The same procedure for punching-out the ply pattern was used with the stainless steel mesh/Al tape to obtain the required insert and surface plies. Figure 9 shows the rolled tape, the steel-rule die bond, the as-cut mesh, and typical completed insert plies.

All plies were laid out on an assembly check board (Figure 10) and a photograph taken of each blade ply assembly. In this manner, a permanent record was kept of the plies incorporated in each blade. The plies then were assembled in the shuttle box with 0.12 mm (0.005 inch) T50-coated sacrificial sheets of 2024 aluminum placed on the outer layers of both the concave and the convex surface to provide uniform pressure during the cycle. The shuttle box concept was a unique process innovation; the box served as a ply assembly container, a press location fixture, and a matrix box for machining the consolidated blade. Figure 11 shows a partial assembly of the plies in the shuttle box; nearby are the remaining plies, lined up and awaiting assembly. The three dovetail locating notches can be seen, so can the notch at the blade tip. A fully assembled set of plies within the shuttle box is shown in Figure 12. Here, one of the shuttle box sides was removed to observe the ply stacking arrangement. The fully loaded shuttle box was then closed off on the top and bottom with plexiglass covers and shipped to the press area for hot-pressing.

2.2.6 Consolidation - Hot-Pressing

The hot-pressing operation consisted of matched metal die consolidation of the boron/aluminum ply pattern assemblies in a heated, platen-type vacuum hot press using a shuttle box die design.



PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS	PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS	PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS	PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS	PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS	PLY OR LAM NO	ORIENTATION ANGLE IN DEGREES	WEIGHTS
1A	90°		32A	WIRE MESH		49-14	WIRE MESH		74-27	WIRE MESH		98-40	WIRE MESH		[illegible]	WIRE MESH	
2A-A	.005 AL		33A	WIRE MESH		50-14	WIRE MESH		75-27	WIRE MESH		99-40	WIRE MESH		[illegible]	WIRE MESH	
3A-A	.005 AL		34A	WIRE MESH		51-14	WIRE MESH		76-27	WIRE MESH		100-40	WIRE MESH		[illegible]	WIRE MESH	
4A-A	.005 AL		35A	WIRE MESH		52-14 / 52-14-A / 53-14	WIRE MESH / .010 AL / WIRE MESH		77-27	WIRE MESH		101-40	WIRE MESH		[illegible]	WIRE MESH	
5A-A	.005 AL		36A	WIRE MESH					77-27-A	.005 AL		102-40	WIRE MESH		[illegible]	WIRE MESH	
6A	WIRE MESH		37A	WIRE MESH		54-14	WIRE MESH		78-27	WIRE MESH		103-40	WIRE MESH		[illegible]	WIRE MESH	
7A	WIRE MESH		38A	WIRE MESH		55-14	WIRE MESH		79-27	WIRE MESH		[illegible]	.010 AL		[illegible]	WIRE MESH	
8A	WIRE MESH		A	WIRE MESH		56-14	WIRE MESH		80-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
9A	WIRE MESH		1	0°		57-14	WIRE MESH		81-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
10A	WIRE MESH		2	-22°		58-14	WIRE MESH		82-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	.005 AL	
11A	WIRE MESH		3	WIRE MESH		59-14	WIRE MESH		83-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
12A	WIRE MESH		4	0°		60-14	WIRE MESH		84-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
13A	WIRE MESH		5	+22°		61-14	WIRE MESH		85-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
14A	WIRE MESH		6	0°		62-14	WIRE MESH		86-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
15A	WIRE MESH		7	-22°		63-14	WIRE MESH		87-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
16A	WIRE MESH		8	0°		64-14	WIRE MESH		88-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
17A	WIRE MESH		9	+22°		64-14-A	.010 AL		89-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
18A	WIRE MESH		10	0°		15	0°		90-27	WIRE MESH		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
19A	WIRE MESH		11	-22°		16	0°		28	0°		[illegible]	WIRE MESH		[illegible]	WIRE MESH	
20A	WIRE MESH		12	0°		17	0°		29	0°		41	0°		[illegible]	WIRE MESH	
21A	WIRE MESH		13	+22°		18	0°		30	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
22A	WIRE MESH		14	0°		19	0°		31	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
23A	WIRE MESH		39-14	WIRE MESH		20	0°		32	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
24A	WIRE MESH		40-14	WIRE MESH		21	0°		33	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
25A	WIRE MESH		41-14	WIRE MESH		22	0°		34	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
26A	WIRE MESH		42-14	WIRE MESH		23	0°		35	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
26A-A	.005 AL		43-14	WIRE MESH		24	0°		36	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
27A	WIRE MESH		44-14	WIRE MESH		25	0°		37	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
28A	WIRE MESH		45-14	WIRE MESH		26	0°		38	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
29A	WIRE MESH		46-14	WIRE MESH		27	0°		39	0°		[illegible]	[illegible]		[illegible]	WIRE MESH	
30A	WIRE MESH		47-14	WIRE MESH		65-27	WIRE MESH		40	0°		[illegible]	[illegible]		[illegible]	.005 AL	
31A	WIRE MESH		48-14	WIRE MESH		66-27	WIRE MESH		40-A	.005 AL		[illegible]	WIRE MESH		[illegible]	.005 AL	
						67-27	WIRE MESH		91-40	WIRE MESH		[illegible]	[illegible]		[illegible]	.005 AL	
						68-27	WIRE MESH		92-40	WIRE MESH		[illegible]	[illegible]		[illegible]	.005 AL	
						69-27	WIRE MESH		93-40	WIRE MESH		[illegible]	WIRE MESH		[illegible]	.005 AL	
						70-27	WIRE MESH		94-40	WIRE MESH		[illegible]	WIRE MESH				
						71-27	WIRE MESH		95-40	WIRE MESH		[illegible]	WIRE MESH				
						72-27	WIRE MESH		96-40	WIRE MESH		[illegible]	WIRE MESH				
						73-27	WIRE MESH		97-40	WIRE MESH		[illegible]	WIRE MESH				

+ DIRECTION OF PLY IS TOWARD TRAILING EDGE OF BLADE

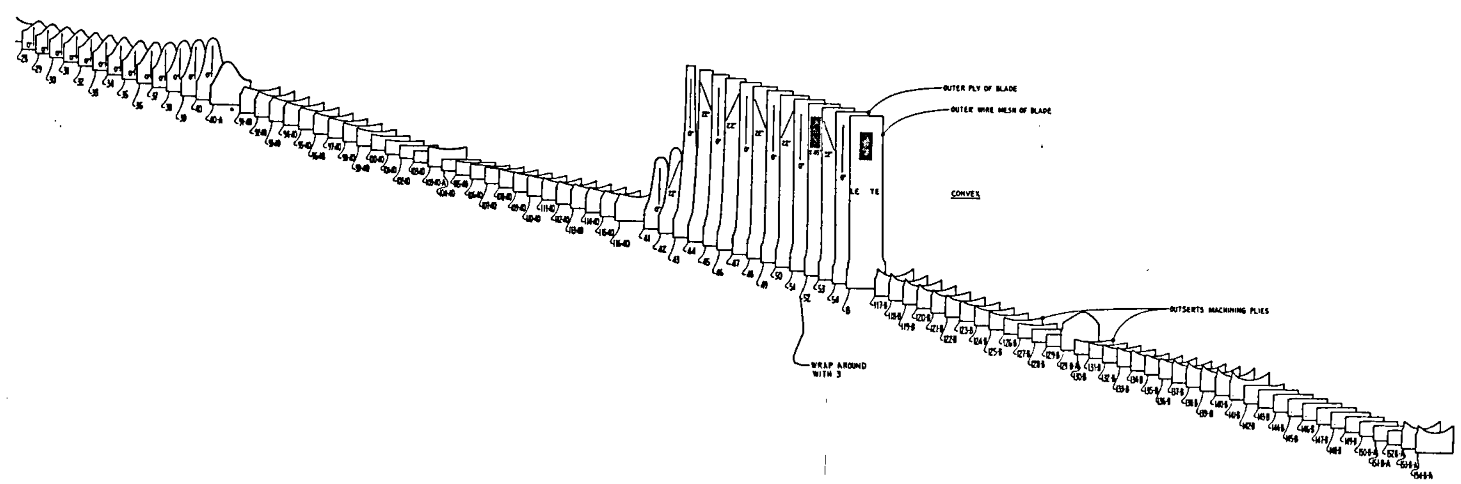


Figure 6. Ply Orientation and Layup Sequence.

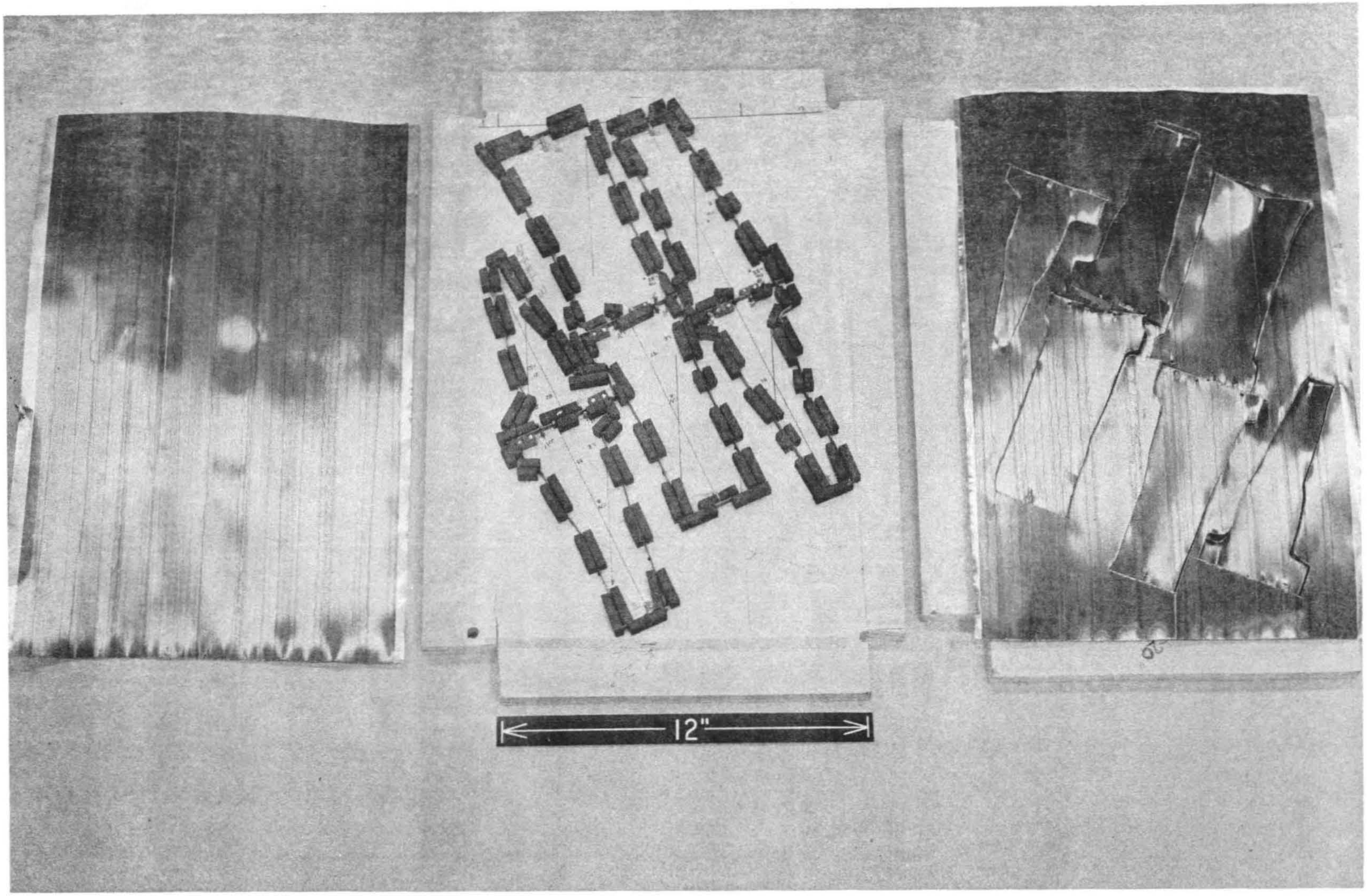


Figure 7. Typical Steel Rule Clicker Dies, Center, Used to Punch Out the B/Al Ply Patterns.

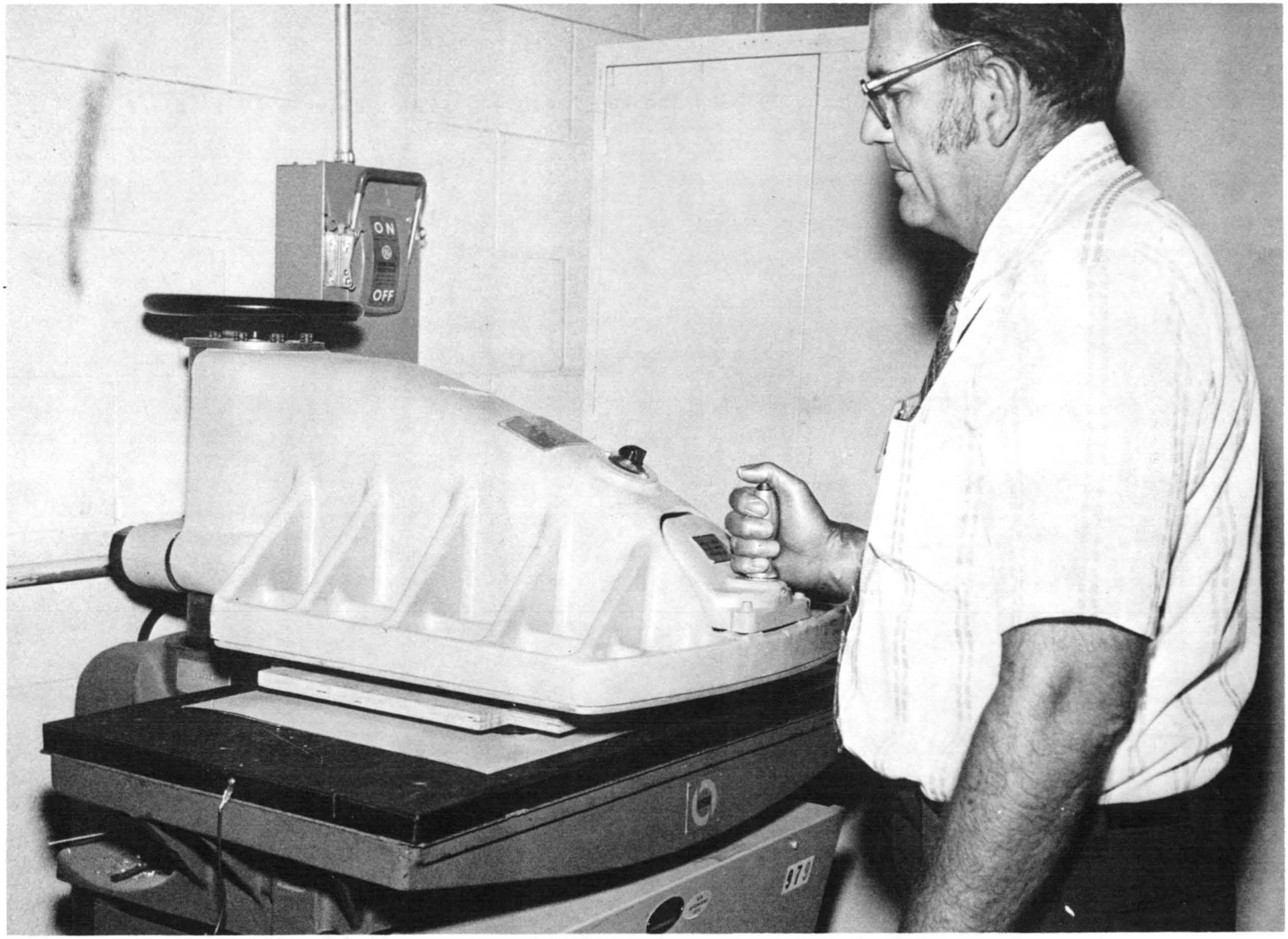


Figure 8. Clicker Press for Punching Out the B/Al Ply Patterns.

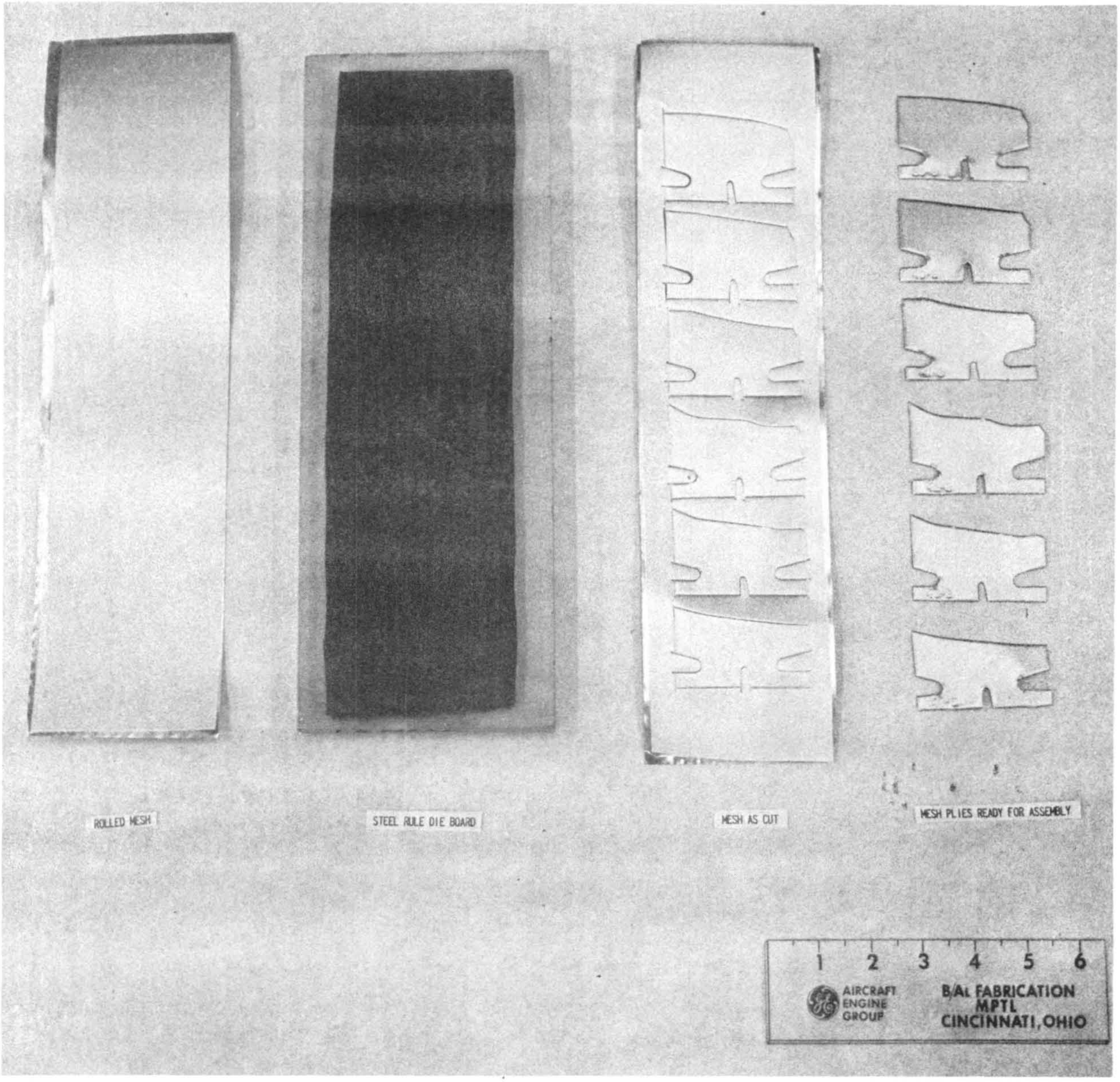


Figure 9. Sequence in Forming the SS Mesh/Al Root Plies.

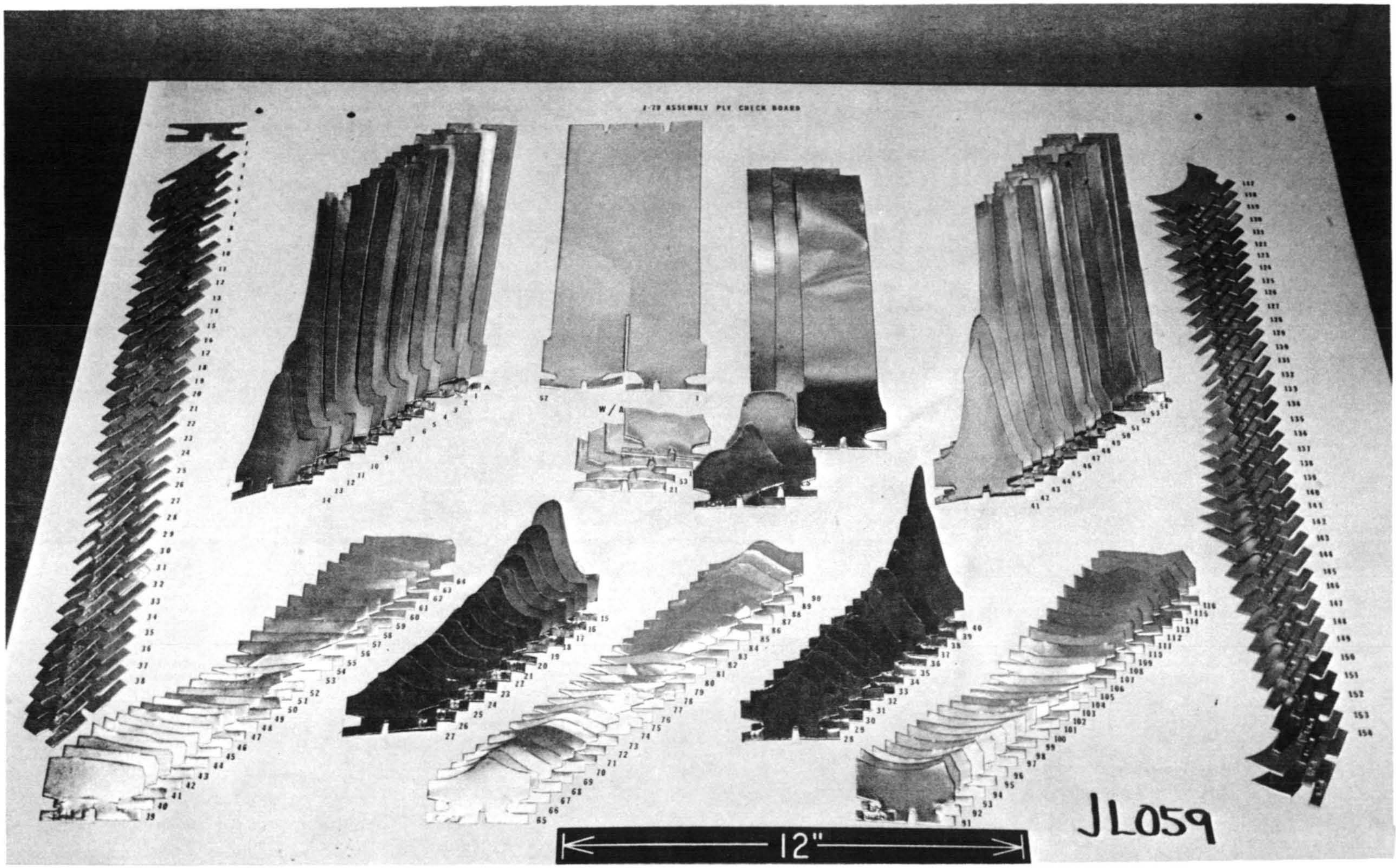


Figure 10. Layout of All Plies on Ply Assembly Check Board.

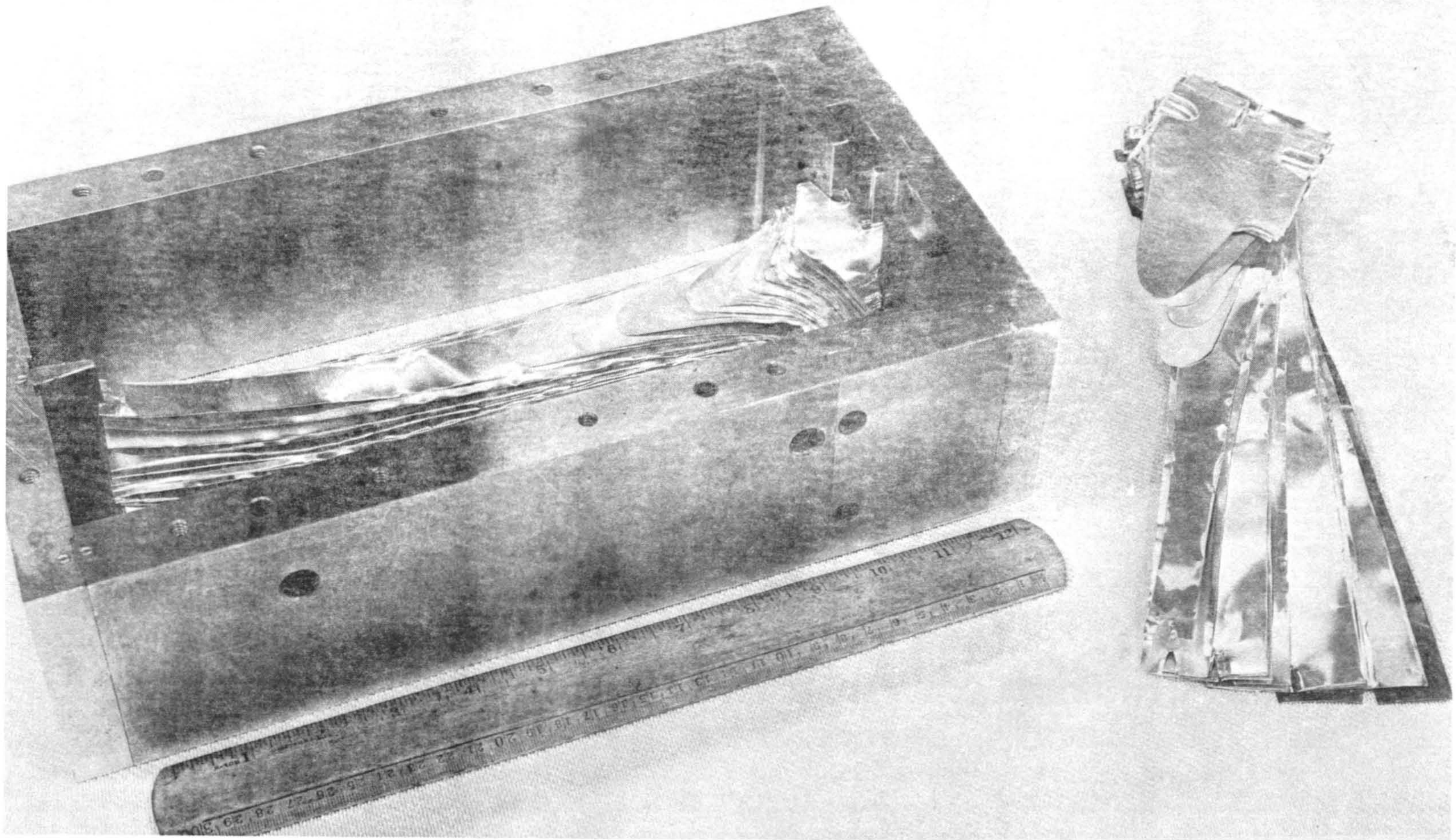


Figure 11. Partial Assembly of Plies in the Matrix Box Illustrating the Ply Contours and Locations Points.

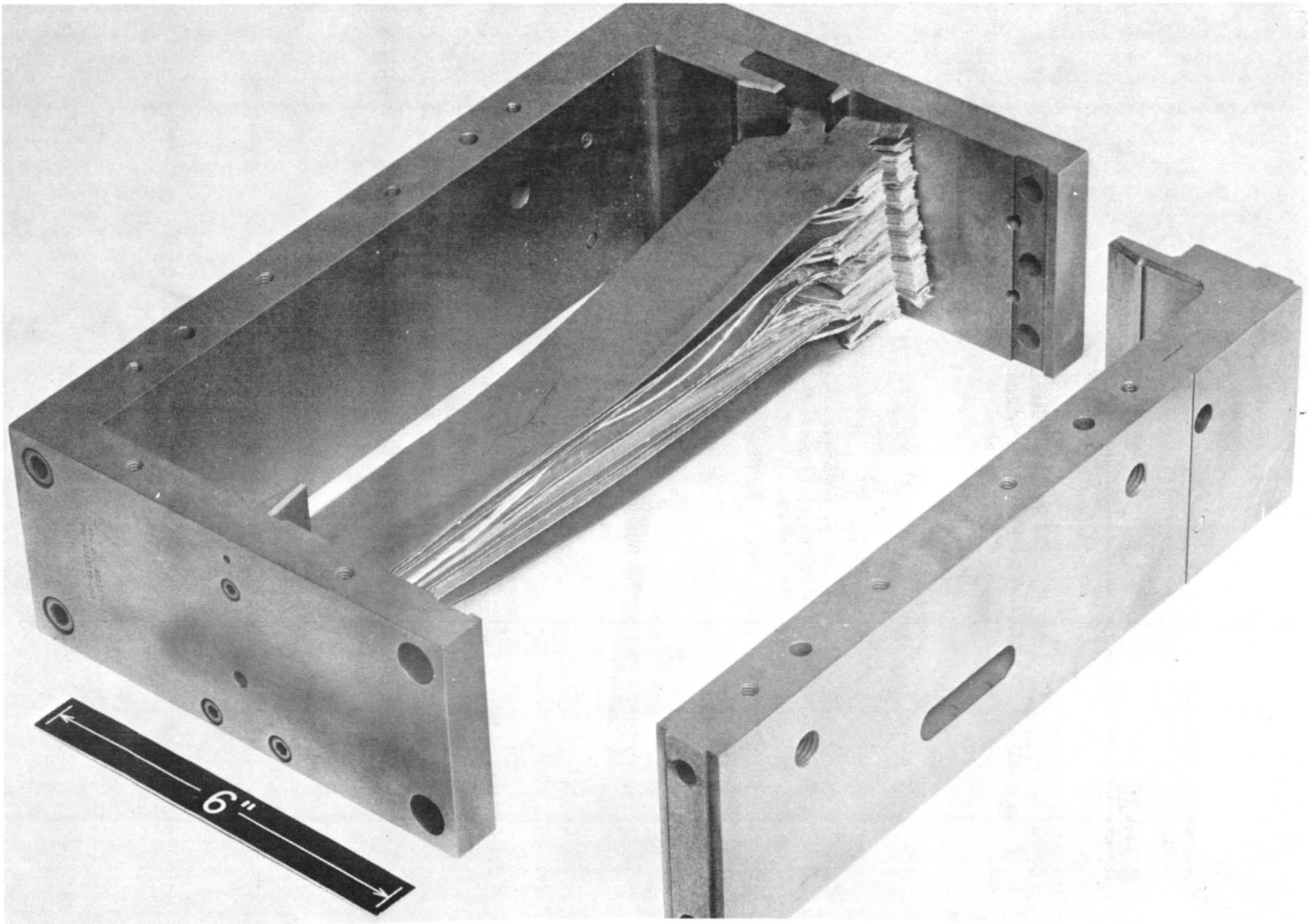


Figure 12. Plies Assembled in the Shuttle Box with One Side Removed to Observe Ply Stacking Arrangement.

2.2.6.1 Shuttle Box Die Design

The previously developed shuttle box concept was unique in that it enabled the die and consolidated blade to maintain a constant point-to-point relationship while allowing greater ease in fabricating the blade. To illustrate this point, a comparison with the earlier hot-pressing die is helpful. The shuttle box die design is discussed later in this section.

In earlier hot-pressing of dovetail specimens and development blades, multisectional dies were used. A photograph of the earlier hot-pressing die is shown in Figure 13. With this earlier pressing concept, the procedures were more difficult. As part of this process, pins were used to mark designated locations on the blade, and the entire die had to be disassembled on the work bench. The ply pattern assemblies were then loaded into the die and the die reassembled. Next, the assembly was picked up with a mechanical lift, transported to the press, loaded into the press, and heated to hot-pressing temperature. This required a heating time of 6 to 8 hours. Cooling down to room temperature after blade consolidation required another 10 to 12 hours.

Following the consolidation cycle, the die was removed from the press, again using a mechanical lift, and transported to the work bench. The die was then disassembled and the blade removed.

Such a hot-pressing cycle required a total time of 16 to 20 hours and permitted consolidation of only one blade per day per press. While this was tolerable during earlier specimen and blade development programs, it was inadequate for the current program. The shuttle box die design used in this program shortened this consolidation time considerably.

The shuttle box die design allowed a ply pattern assembly to be loaded into a hot die, preheated to 371° C (700° F), that could be permanently affixed to the hot platens in the vacuum press. Moreover, this arrangement provided for more accurate reference locations to mold the sections of the airfoil in the finished state. The matched metal-die shuttle-box assembly, which incorporated features to accomplish a shorter cycle and provide for better positioning, is shown in exploded view in Figure 14.

The matched metal-die halves, as shown in Figure 15, were permanently secured in position by being bolted to the top and bottom press platens, respectively. The guide pins provided for accurate alignment between the top die shoe and the bottom die shoe, thereby closely aligning the die faying surfaces. The virtue of this pressing process lies in using the shuttle box as the location/matrix box. Able to be accurately positioned on the lower die, this shuttle box provides the female features into which the upper die can be inserted and accurately positioned. The shuttle box with the ply patterns assembled in position can be positioned in the lower die easily even at temperatures of up to 371° C (700° F).

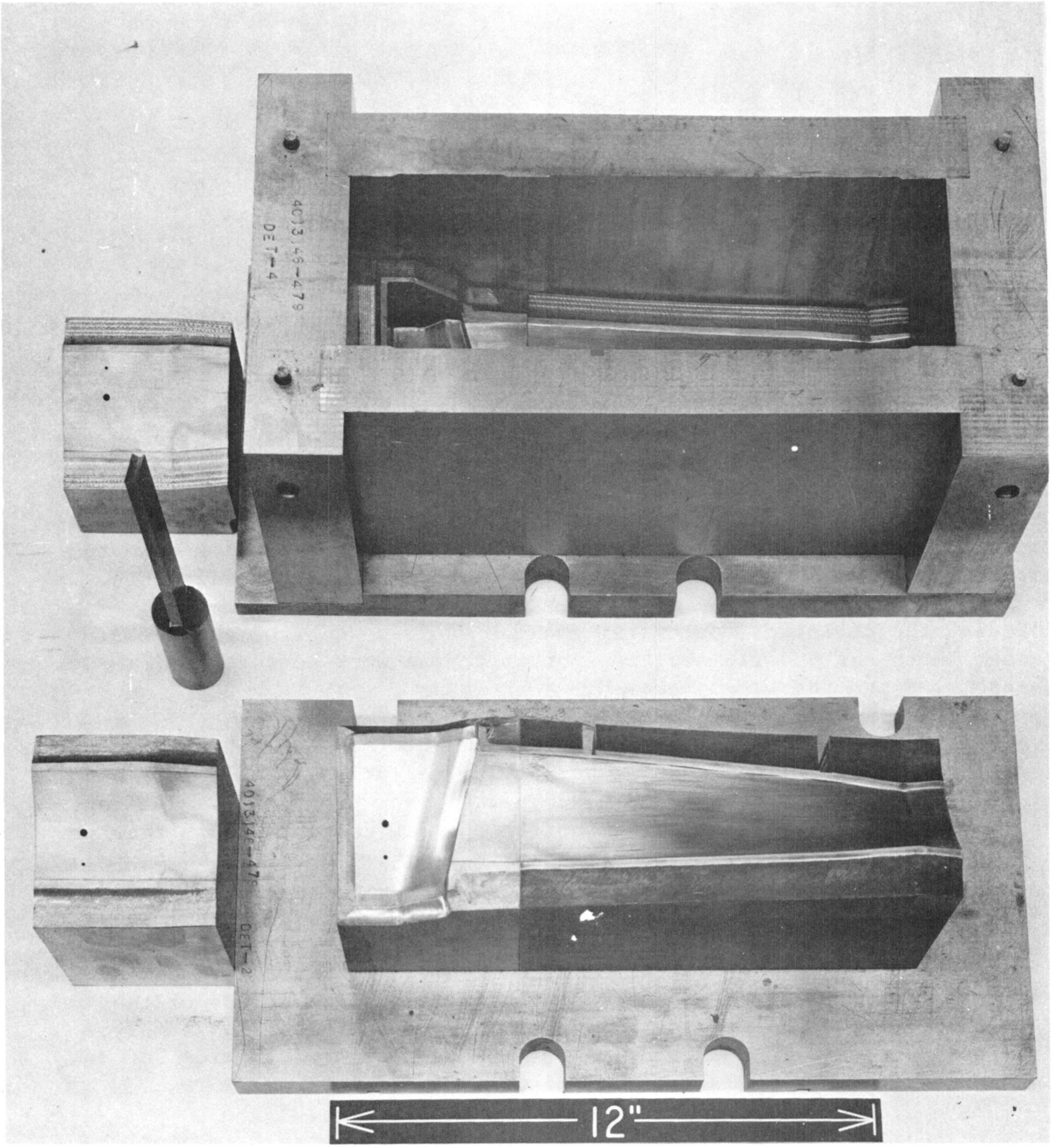


Figure 13. Early Die Showing the Male and Female Die Blocks With Replaceable Root Sections.

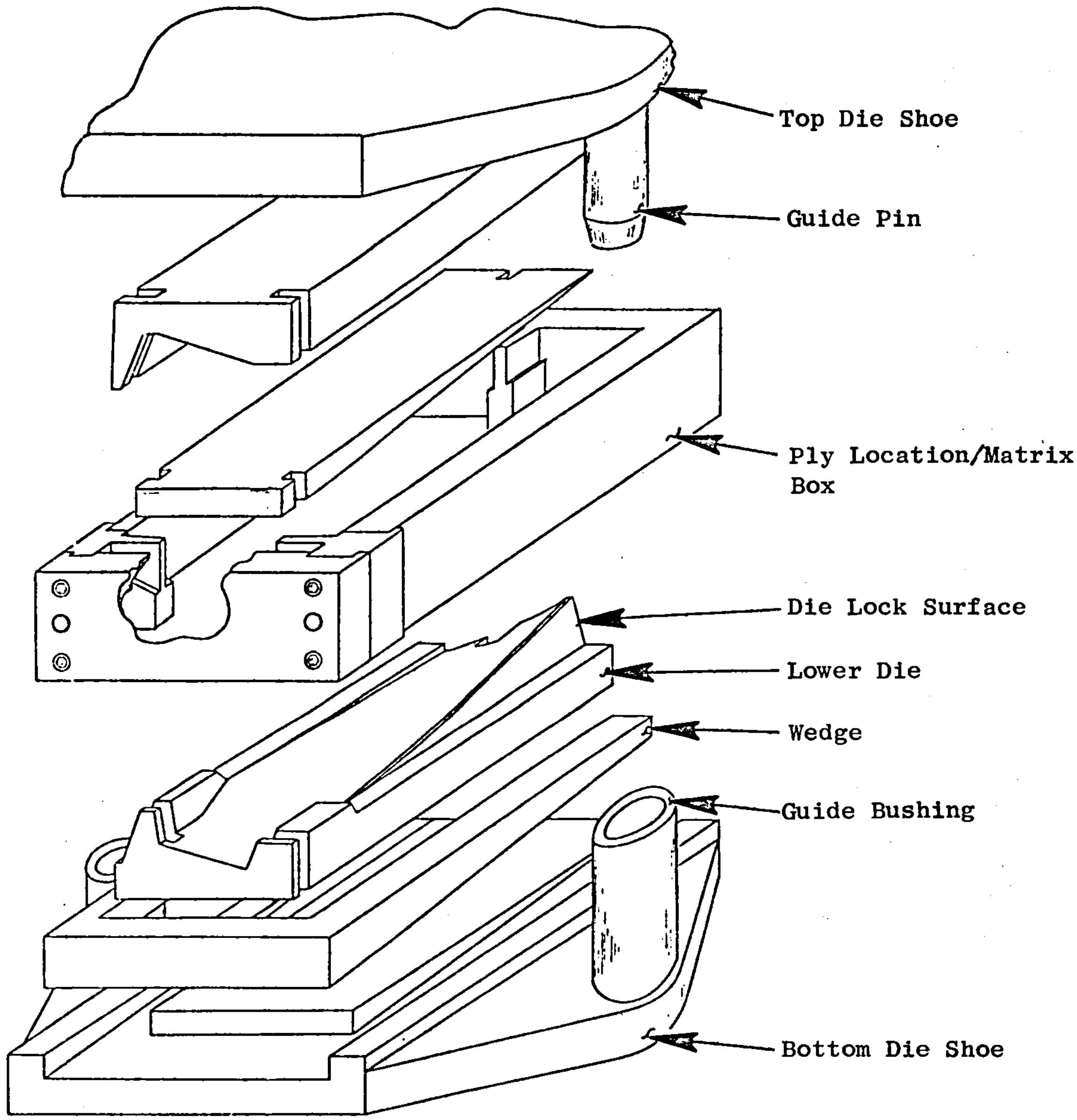


Figure 14. J79 Stage 1 Compressor B/Al Blade Pressing Die.

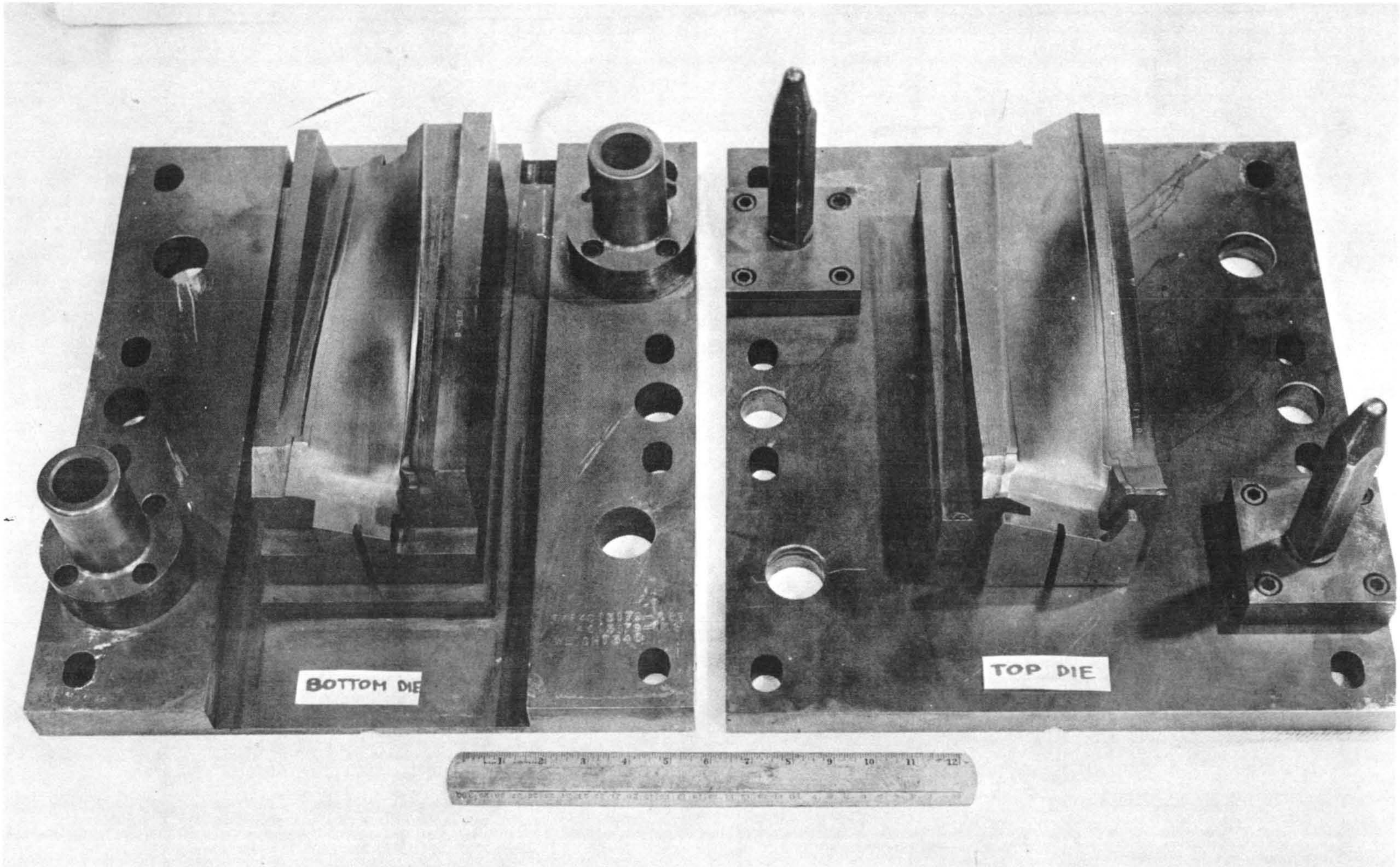


Figure 15. J79 Stage 1 Compressor B/Al Blade Die Set.

As a result of the shuttle box use in the hot die, the heating-up cycle to hot-pressing temperature took less than an hour, and the cooling-down cycle after consolidation was accomplished overnight. All blades in this program were fabricated using the overnight cool-down cycle. Had the argon-cooled fans been used, however, cooling down to 204° C (400° F) would have taken as little as 1 or 2 hours.

2.2.6.2 Hot Press Equipment

The vacuum hot presses used for consolidating the boron/aluminum ply pattern assemblies are shown in Figure 16. The basic press is a 250-ton Williams and White four-poster press, modified by adding a vacuum chamber with a pumping system capable of obtaining a vacuum of 13.3 mPa (10^{-6} torr). The original hot platens inside the vacuum chamber were made of graphite and were heated by tubular molybdenum resistance heaters inside of holes just under the surface of the graphite platens. However, the press was modified in an earlier program. Stainless steel platens with cartridge-type, Inconel-sheathed, nichrome-wire resistance heaters in holes just under the pressing surface of the platens were used in both of the Williams and White presses.

2.2.6.3 Consolidation

In the consolidation cycle, the die was preheated to 371° C (700° F). Then the shuttle box, containing the B/Al ply pattern assembly, was positioned on the lower die, and the upper die was brought down into contact with the plies. In the same operation, the vacuum chamber was sealed and evacuated. This operation took about 15 minutes. The die, the plies, and the shuttle box were rapidly heated to the desired 493° C (920° F) and held at that temperature for 35 minutes. Complete consolidation of the boron/aluminum ply pattern assembly was attained by application of a 881 kN (198,000 lbf) load, 48.26 MPa (7000 psi), to the bimetal blade. For the all 1100Al matrix blade, the pressure was increased to 55.15 MPa (8000 psi); for the ATAC Al matrix blade it was decreased to 41.36 MPa (6000 psi). Following the press cycle, the power was turned off, and the consolidated blade was cooled in a vacuum under pressure. The shuttle box, with the molded blade intact, was then removed from the die.

During the consolidation cycle, all data regarding time, die temperature, chamber vacuum and pressure, load on part, and press travel were recorded on a Process Data Sheet like the one shown in Figure 17. A typical consolidation cycle is shown on the graph in Figure 18. A summary of all consolidation process data for all the J79 B/Al blades accounted for in this program is tabulated in Table VII.

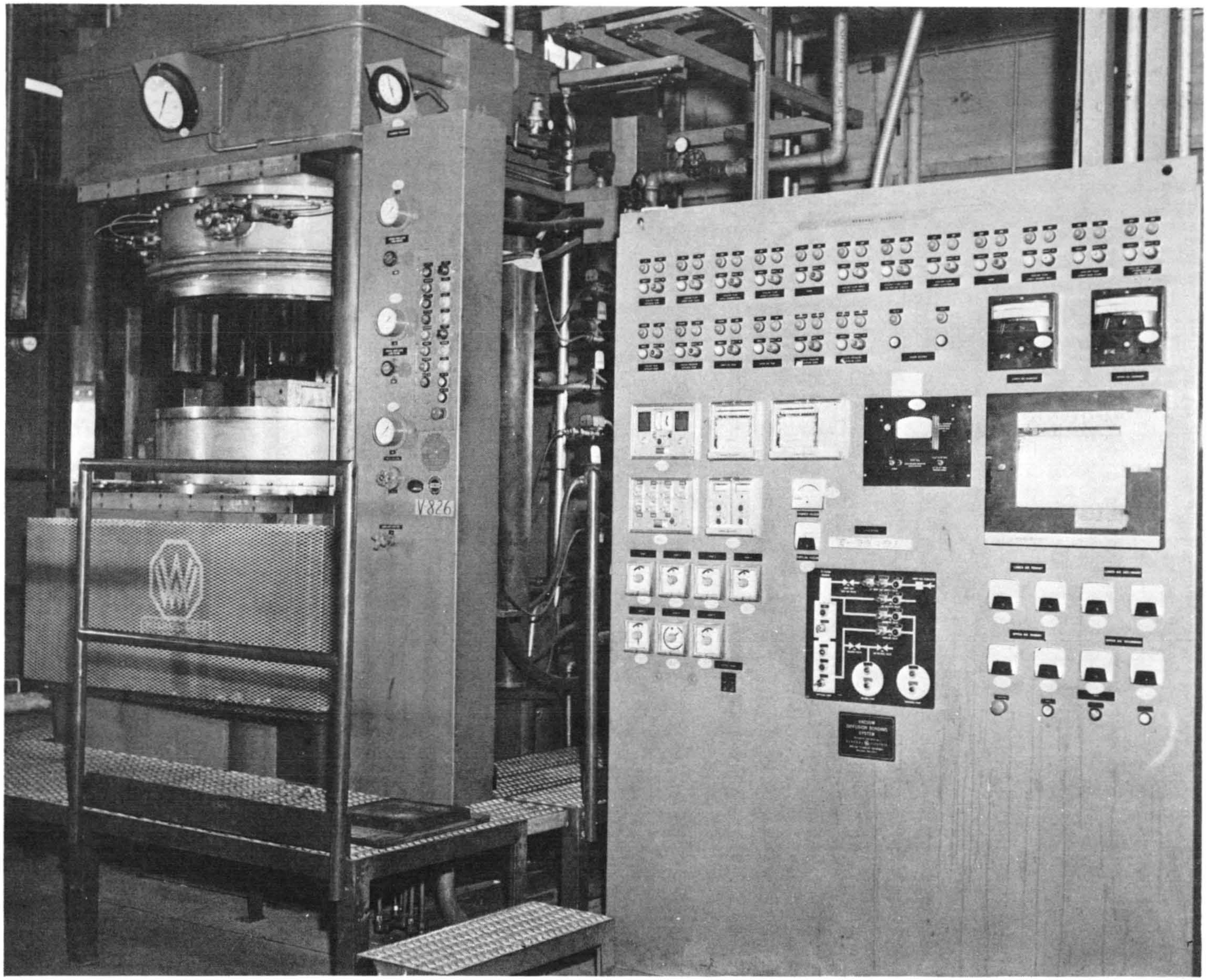


Figure 16. Williams & White - Vacuum Hot Press and Controls.

I-J-79 PROGRAM
PROCESS DATA SHEET CJ79-SSC(211R-1T)-1T4

Oper No. 50	Operation: Vacuum Hot Press	Part Name: B/Al Blade IJ79 Compressor Rotor, Stage 1								Part No. 4013179-420		Serial No. -1T4
Time	Event	Lower die temp °F			Upper die temp °F			Chamber		Load	Dial Gage Reading	Operator Badge No.
		TC	TC	TC	TC	TC	TC	Vac.	Pres.			
11:30	DIE HEAT UP	745	775	775	770	780	780					T. JONES
	VACUUM OFF, FILL CHAMBER WITH ARGON, OPEN CHAMBER,											#15980
	MATRIX BOX INSTALLED IN DIE, CHAMBER CLOSED AND PUMPED DOWN.											
1150	DIE HEAT UP	650	695	695	695	715	712	4.2×10^{-4}			.192	
1220	20,000 LB. LOAD	625	665	665	675	680	680	3.4×10^{-4}			.426	
1300	50,000 LB LOAD	815	770	770	700	780	780	2.8×10^{-4}			.532	
1322	100,000 LB. LOAD										.544	
1324	150,000 LB. LOAD										.550	
1325	198,400 LB. LOAD	850	850	850	860	850	850	2.8×10^{-4}			.556	
	(FULL LOAD, 7KSI)											
1355	START TIME @ TEMP.	920	920	920	918	920	920	2.6×10^{-4}			.556	
1400		922	922	922	920	922	920	2.6×10^{-4}			.556	
1405		922	925	925	920	925	920	2.6×10^{-4}			.560	
1410		922	925	925	920	925	920	2.6×10^{-4}			.562	
1415		922	925	925	920	925	920	2.6×10^{-4}			.562	
1420		920	922	922	920	922	920	2.6×10^{-4}			.562	
1425		920	922	922	920	920	920	2.6×10^{-4}			.562	
1430	END OF CYCLE - 35 MIN.	920	922	922	920	920	920	2.6×10^{-4}			.562	
1431	COOL DOWN UNDER VACUUM & FULL LOAD.											

Press No. V-825 Die Set No. 2 Matrix Box No. B Date Pressed 12-3-77 Date Unloaded 12-5-77

Comments: PREHEAT DIE TO 700°F, FILL CHAMBER WITH ARGON, OPEN CHAMBER AND PLACE MATRIX BOX IN DIE, CLOSE CHAMBER AND PUMP DOWN, QUICK HEAT UP CYCLE IN VACUUM. PRESS CYCLE 920°F $^{+10}_{-0}$ / 35 MIN. / 7KSI. APPLY FULL LOAD @ 850°F AND VACUUM IN 10^{-4} RANGE. COOL DOWN UNDER VACUUM AND FULL LOAD.

Figure 17. Typical Vacuum Hot Press Process Data Sheet for Consolidation of Blade.

• Group 2

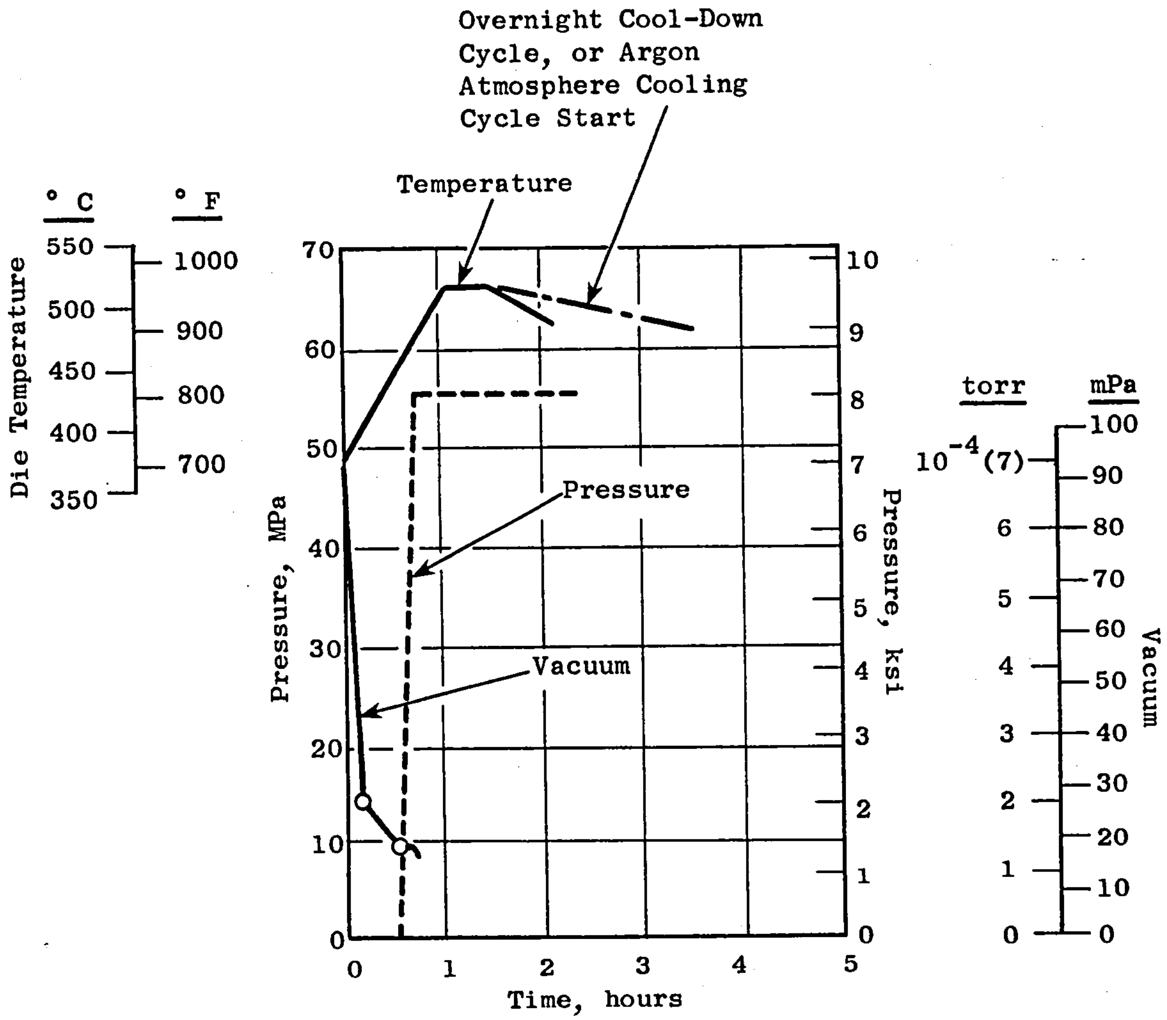


Figure 18. Typical Consolidation Cycle of a J79 Stage 1 Compressor B/Al Blade.

Table VII. **Summary of Data on Rapid Bond Cycle Vacuum Hot-Pressing of X, S, T, and L B/Al Blades.**

Blade S/N	Start Avg. Die Temperature, °C	Start Avg. Die Temperature, °F	Time Before Max Load Applied, minutes	Load at Full Pressure, MN	Load at Full Pressure, ton	100% Load: Start Avg. Die Temperature, °C	100% Load: Start Avg. Die Temperature, °F	100% Load: Finish Avg. Die Temperature, °C	100% Load: Finish Avg. Die Temperature, °F	100% Load: Time at Temperature, minutes	100% Load: Best Vacuum, μm	Press Ram Movement, cm	Press Ram Movement, in.
X1	373	704	70	0.758	85.2	417	782	490	914	35	0.18	0.925	0.346
X2	374	706	65	0.758	85.2	412	773	496	924	35	0.32	1.085	0.427
X3	362	683	70	0.758	85.2	406	762	497	926	35	0.35	1.057	0.416
X4	393	739	110	1.011	113.6	447	836	492	917	35	0.22	1.168	0.460
X5	377	711	97	1.011	113.6	453	847	494	922	35	0.24	1.135	0.447
X6	395	743	85	0.758	85.2	451	844	496	924	35	0.22	1.140	0.449
X7	348	659	78	0.758	85.2	450	842	493	919	35	0.24	1.194	0.470
X8	367	693	105	1.011	113.6	442	827	494	922	35	0.20	1.052	0.414
X9	351	663	95	0.882	99.2	437	819	493	920	35	0.22	1.204	0.474
X10	334	633	115	0.882	99.2	446	835	492	917	35	0.22	1.201	0.473
X11	375	707	143	0.882	99.2	450	842	497	927	35	0.26	1.113	0.435
1S1	403	757	115	0.882	99.2	462	863	496	925	35	0.30	0.983	0.387
1S2	394	742	131	0.882	99.2	462	863	496	925	35	0.38	0.975	0.384
1S3	357	674	131	0.882	99.2	456	852	493	920	35	0.12	0.975	0.384
1S4	388	730	145	0.882	99.2	453	848	495	923	35	0.20	0.950	0.374
1S5	378	712	95	0.882	99.2	457	855	493	920	35	0.18	1.008	0.397
1S6	401	753	145	0.882	99.2	467	872	495	923	35	0.20	0.947	0.373
1S7	378	713	119	0.882	99.2	454	850	494	921	35	0.14	0.940	0.370
1S8	420	788	110	0.882	99.2	452	846	494	922	35	0.14	0.955	0.376
2S1	438	821	82	0.882	99.2	461	861	497	927	35	0.42	0.831	0.327
2S2	364	688	105	0.882	99.2	453	847	493	920	35	0.36	0.853	0.336
2S3	368	695	110	0.882	99.2	454	850	494	921	35	0.10	0.831	0.327
2S4	369	697	110	0.882	99.2	456	852	494	922	35	0.12	0.848	0.334
2S5	429	804	90	0.882	99.2	458	856	494	921	35	0.14	0.810	0.319
2S6	394	742	104	0.882	99.2	456	853	496	924	35	0.16	0.739	0.291
2S7	368	695	110	0.882	99.2	456	853	495	923	35	0.12	0.853	0.336
2S8	429	805	118	0.882	99.2	457	854	494	922	35	0.14	0.843	0.332
2S9	379	714	103	0.882	99.2	458	857	493	921	35	0.10	0.772	0.304
2S10	404	760	98	0.882	99.2	460	860	494	922	35	0.17	0.917	0.361
1T1	377	710	123	0.882	99.2	459	858	497	927	35	0.26	0.937	0.369
1T2	413	776	123	0.882	99.2	461	862	495	923	35	0.28	0.940	0.370
1T3	321	610	118	0.882	99.2	463	865	495	923	35	0.26	0.935	0.368
1T4	411	771	115	0.882	99.2	456	852	494	921	35	0.26	0.940	0.370
1T5	389	733	128	0.882	99.2	456	852	497	926	35	0.28	0.747	0.294
1T6	359	678	118	0.882	99.2	456	853	497	926	35	0.28	0.699	0.275
1T7	369	697	108	0.882	99.2	456	852	494	922	35	0.28	0.665	0.262
1T8	378	712	128	0.882	99.2	469	877	495	923	35	0.28	0.782	0.308
1T9	383	722	118	0.882	99.2	469	876	497	927	35	0.28	0.790	0.311
1T10	402	755	120	0.882	99.2	456	852	496	925	35	0.30	0.798	0.314
1T11	348	658	120	0.882	99.2	462	864	495	923	35	0.30	0.818	0.322
1T12	379	714	115	0.882	99.2	458	856	497	926	35	0.30	0.798	0.314
1T13	371	700	117	0.882	99.2	464	868	494	922	35	0.30	0.780	0.307
1T14	391	736	115	0.882	99.2	464	868	497	926	35	0.30	0.780	0.307
1T15	387	728	110	0.882	99.2	464	868	497	927	35	0.30	0.800	0.315
1T16	388	730	120	0.882	99.2	464	867	497	927	35	0.28	0.737	0.290
1T17	403	758	115	0.882	99.2	457	854	497	926	35	0.28	0.734	0.289

Table VII. Summary of Data on Rapid Bond Cycle Vacuum Hot-Pressing of X, S, T, and L B/Al Blades (Concluded).

Blade S/N	Start Avg. Die Temperature,		Time Before Max Load Applied, minutes	Load at Full Pressure,		100% Load						Press Ram Movement,	
						Start Avg. Die Temperature,		Finish Avg. Die Temperature,		Time at Temperature, minutes	Best Vacuum, µm		
	°C	°F		MN	ton	°C	°F	°C	°F			cm	in.
1T18	387	728	110	0.882	99.2	402	756	498	928	35	0.30	0.752	0.296
1T19	394	741	125	0.882	99.2	457	855	497	927	35	0.30	0.808	0.318
1T20	379	714	120	0.882	99.2	456	853	497	927	35	0.30	0.805	0.317
1T21	402	755	115	0.882	99.2	461	861	497	927	35	0.30	0.790	0.311
1T22	370	698	120	0.882	99.2	457	855	497	927	35	0.30	0.833	0.328
1T23	372	702	115	0.882	99.2	464	867	497	926	35	0.30	0.798	0.314
1T24	392	737	108	0.882	99.2	465	869	498	929	35	0.30	0.808	0.318
1T25	377	711	112	0.882	99.2	462	863	495	923	35	0.30	0.805	0.317
1T26	370	698	105	0.882	99.2	464	868	497	926	35	0.30	0.742	0.292
1T27	371	700	115	0.882	99.2	466	870	496	925	35	0.30	0.805	0.317
1T28	387	728	115	0.882	99.2	459	858	496	924	35	0.30	0.737	0.290
1T29	378	713	113	0.882	99.2	464	867	497	926	35	0.30	0.805	0.317
1T30	390	734	110	0.882	99.2	471	880	497	926	35	0.30	0.767	0.302
1T31	391	736	110	0.882	99.2	467	873	497	926	35	0.30	0.765	0.301
1T32	370	698	95	0.882	99.2	471	879	497	927	35	0.30	0.785	0.309
1T33	366	690	113	0.882	99.2	456	852	496	924	35	0.30	0.757	0.298
1T34	358	676	115	0.882	99.2	460	860	497	926	35	0.30	0.739	0.291
1T35	377	711	105	0.882	99.2	461	862	497	927	35	0.30	0.820	0.323
L0001	364	687	115	0.882	99.2	461	862	497	927	35	0.30	0.881	0.347
L0002	370	698	105	0.882	99.2	473	883	498	929	35	0.30	0.874	0.344
L0003	395	743	105	0.882	99.2	463	865	496	925	35	0.30	0.808	0.318
L0004	398	748	111	0.882	99.2	460	860	498	928	35	0.30	0.856	0.337
L0005	391	736	95	0.882	99.2	462	863	496	924	35	0.30	0.808	0.318
L0006	391	736	108	0.882	99.2	459	858	498	928	35	0.30	0.836	0.329
L0007	453	848	102	0.882	99.2	460	860	498	928	35	0.30	0.843	0.332
L0008	405	761	103	0.882	99.2	458	856	498	928	35	0.30	0.780	0.307
L0009	383	721	100	0.882	99.2	457	855	498	928	35	0.30	0.790	0.311
L0010	389	733	105	0.882	99.2	459	858	498	928	35	0.30	0.818	0.322
L0011	370	698	113	0.882	99.2	456	852	498	928	35	0.30	0.831	0.327
L0012	397	747	110	0.882	99.2	457	855	497	927	35	0.30	0.826	0.325
L0013	383	722	108	0.882	99.2	457	855	498	928	35	0.30	0.754	0.297
L0014	379	715	124	0.882	99.2	464	867	497	926	35	0.30	0.838	0.330
L0015	356	672	120	0.882	99.2	457	855	497	927	35	0.30	0.726	0.286
1L001	397	747	96	0.882	99.2	459	859	496	924	35	0.30	0.826	0.325
1L002	378	712	112	0.882	99.2	458	857	496	924	35	0.30	0.886	0.349
1L003	795	743	100	0.882	99.2	458	857	496	924	35	0.30	0.833	0.328
1L004	360	680	115	0.882	99.2	457	855	497	926	35	0.30	0.861	0.339
1L005	399	750	97	0.882	99.2	465	869	494	922	35	0.30	0.752	0.296
1L006	378	712	85	0.882	99.2	471	880	494	922	35	0.30	0.759	0.299
1L007	379	715	105	0.882	99.2	460	860	496	925	35	0.30	0.759	0.299
1L008	395	743	112	0.882	99.2	460	860	499	930	35	0.30	0.754	0.297
1L009	381	717	115	0.882	99.2	460	860	495	923	35	0.30	0.848	0.334
1L010	402	755	115	0.882	99.2	462	863	497	926	35	0.30	0.785	0.309
1L011	389	733	110	0.882	99.2	460	860	494	921	35	0.30	0.841	0.331
1L012	398	748	117	0.882	99.2	462	863	498	929	35	0.30	0.861	0.339
1L013	378	713	120	0.882	99.2	458	857	496	925	35	0.30	0.826	0.325
1L014	403	758	104	0.882	99.2	457	854	496	924	35	0.30	0.925	0.364
1L015	380	716	112	0.882	99.2	456	852	495	923	35	0.30	0.846	0.333

2.2.7 Clean and Bench

A spatula and pliers were used to remove the sacrificial sheets from each side of the molded blade. The filament sample was then removed from the flat root area of the molded blade. These boron filaments subsequently were tensile tested and the results evaluated in reference to the consolidation cycle temperature data. (Low filament strength from consolidated blades would indicate overtemperature of the part during consolidation.) The molded blade in the shuttle box was lightly grit-blasted with 150-grit aluminum oxide powder to remove any residual release agent that might have come from the sacrificial sheet.

2.2.8 Inspection

2.2.8.1 Visual

Once the molded blade in the shuttle box had been grit-blast cleaned, it was inspected visually (unremoved) to ensure that:

- No surface wrinkles or folds had developed on the convex side of the airfoil.

- No surface wrinkles or folds had developed on the concave side of airfoil that were longer than 1.6 mm (1/16 in.) in the chordwise directionor deeper than 0.25 mm (0.01 in.) perpendicular to the surface.

The blade was also checked for any other surface irregularities that would affect meeting the print requirements.

2.2.8.2 Nondestructive Evaluation

All blades were examined nondestructively by through-transmission ultrasonic C-scan. This inspection technique employed a master-blade-contour follower to allow complete airfoil scanning. Details of this ultrasonic inspection procedure are available in Reference 3.

3.0 BLADE DESCRIPTION

As stated earlier, six blade designs (tabulated in Table I) representing two fabricators were evaluated in this program to determine the effect of each design on the impact resistance of the blades. Separate tabulations for each fabricator's blades are presented in Table VIII.

3.1 TRW, INC. FABRICATED BLADES

TRW, Inc. fabricated blades are of two designs, each using B/Al material. These designs have been identified in Tables I and VIII as Designs D and E. The process used is proprietary to TRW, Inc. The main difference between the two designs was in the aluminum matrix materials. Both designs used 0.142 mm (0.0056 in.) diameter boron, a core of 0° oriented B/Al plies, an aluminum foil center ply, and an airfoil primarily of ±15° plies. (See the previously identified ply orientation and layup sequence, Figure 6.) The exception to the ±15° airfoil ply layup was the third B/Al ply lying inward from either side (concave and convex) of the blade. This ply on each side had a 0° orientation and is shown schematically in Figure 6. The two designs fabricated by TRW were:

1. Design D: a matrix made entirely of 1100 Al.
2. Design E: a bimetal design that uses an all-1100 Al matrix in the outer 50% of the airfoil span and an ATAC Al matrix in the blade root and lower 50% of the airfoil span. The ATAC system uses foils of 1100 Al alloy and 2024 Al alloy alternately through the blade thickness.

TRW fabricated several blades, but only eight were procured and transferred to Air Force Program F33657-76-C-0608. These eight blades were considered W series blades. Four were of Design E (all-1100 type) and were designated TJ79-5561-W1, -W10, -W12, and -W14. The other four were of Design D (bimetal-type); these were designated TJ79-556(2/IR-1T)-W13, -W15, -W17, and -W18.

3.2 GENERAL ELECTRIC-FABRICATED BLADES

General Electric fabricated blades came in three B/Al material designs which Tables I and VIII show as Designs A, B, and C. In addition to these original three, the most promising design, B, was fabricated with a slight variation and dubbed Design F. As with the TRW designs, the main difference among the original three GE designs was in the aluminum matrix materials. All four designs utilize 0.142-mm (0.0056 inch) diameter boron, a core of 0° oriented B/Al plies, an aluminum foil center ply, and an airfoil primarily of ±15° plies. (See the previously identified ply orientation and layup

Table VIII. J79 Stage 1 Compressor B/Al Blade Summary, Part Number 4013179-421.

Design	Blade Serial No.	Blade Manufacturing Parameters: Al Matrix Tip	Al Matrix Root	Boron Diameter mm	Boron Diameter (mils)	Layup(1) Angle (°)	Ply Flat Pattern Drawing No.	Process Parameters: Temperature °C	Temperature (°F)	Pressure MPa	Pressure (ksi)	Time, min.
D	TJ79-5561-W1	1100	1100	0.142	(5.6)	±15	4013179-986	493	(920)	55.2	(8)	35
D	TJ79-5561-W10	1100	1100	0.142	(5.6)	±15	-986	493	(920)	55.2	(8)	35
D	TJ79-5561-W12	1100	1100	0.142	(5.6)	±15	-986	493	(920)	55.2	(8)	35
D	TJ79-5561-W14	1100	1100	0 142	(5.6)	±15	-986	493	(920)	55.2	(8)	35
E	TJ79-556(2/1R-1T)-W13	ATAC	1100	0.142	(5.6)	±15	-986	493	(920)	48.3	(7)	35
E	TJ79-556(2/1R-1T)-W15	ATAC	1100	0.142	(5.6)	±15	-986	493	(920)	48.3	(7)	35
E	TJ79-556(2/1R-1T)-W17	ATAC	1100	0.142	(5.6)	±15	-986	493	(920)	48.3	(7)	35
E	TJ79-556(2/1R-1T)-W18	ATAC	1100	0.142	(5.6)	±15	-986	493	(920)	48.3	(7)	35
C	CJ79-5562/1-X1	ATAC	ATAC	0.142	(5.6)	±15	4013266-046	493	(920)	41.4	(6)	35
C	CJ79-5562/1-X2	ATAC	ATAC	0.142	(5.6)	±15	-046	493	(920)	41.4	(6)	35
C	CJ79-5562/1-X3	ATAC	ATAC	0.142	(5.6)	±15	-046	493	(920)	41.4	(6)	35
A	CJ79-5561-X4	1100	1100	0.142	(5.6)	±15	-046	493	(920)	55.2	(8)	35
A	CJ79-5561-X5	1100	1100	0.142	(5.6)	±15	-046	493	(920)	55.2	(8)	35
C	CJ79-5562/1-X6	ATAC	ATAC	0.142	(5.6)	±15	-046	493	(920)	41.4	(6)	35
C	CJ79-5562/1-X7	ATAC	ATAC	0.142	(5.6)	±15	-046	493	(920)	41.4	(6)	35
A	CJ79-5561-X8	1100	1100	0.142	(5.6)	±15	-046	493	(920)	55.2	(8)	35
B	CJ79-556(2/1R-1T)-X9	ATAC	1100	0.142	(5.6)	±15	4013266-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-X10	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-X11	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S3	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S4	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S5	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S6	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S7	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1S8	ATAC	1100	0.142	(5.6)	±15	-047	493	(920)	48.3	(7)	35
F	CJ79-556(2/1R-1T)-2S1	ATAC	1100	0.142	(5.6)	±15	4013266-048	493	(920)	48.3	(7)	35
F	CJ79-556(2/1R-1T)-2S5	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
F	CJ79-556(2/1R-1T)-2S7	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
F	CJ79-556(2/1R-1T)-2S9	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
F	CJ79-556(2/1R-1T)-2S10	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T1)-1T1	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T2)-1T2	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	through						-048					
B	CJ79-556(2/1R-1T)-1T36	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1L1	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	CJ79-556(2/1R-1T)-1L2	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35
B	through						-048					
B	CJ79-556(2/1R-1T)-1L17	ATAC	1100	0.142	(5.6)	±15	-048	493	(920)	48.3	(7)	35

(1)Refer to Figure 6 for core 0°-orientation plies, aluminum centerply, and root filler plies.

sequence, Figure 6.) The exception to the $\pm 5°$ airfoil ply layup was the third B/Al ply located inward from both the concave and convex side of the blade (two places). This ply on each side had a 0° orientation and is shown schematically in Figure 6. The four designs are:

1. Design A: a matrix entirely of 1100 Al.

2. Design B: a bimetal design that uses an all-1100 Al matrix in the outer 50% of the airfoil span and an ATAC Al matrix (alternating two aluminum composition foils of 1100 Al and 2024 Al) in the blade root and lower 50% of the airfoil span.

3. Design C: an all-ATAC Al matrix.

4. Design F: a modification of bimetal Design B to provide for a square filament array.

Blades from both fabricators and of all three material design types (covering Designs A, B, C, D, and E) were consolidated (fabricated) and included in the first series of blades, Series X. Two variations of the bimetal designs (Designs B and F) comprised the second series, Series S. The last two series, T and L, consisted entirely of a single bimetal design, Design F. The four series are discussed in this section. They are:

1. X for experimental blades

2. S for sensitivity blades

3. T for test blades

4. L for L-quality blades

The processing details for the X, S, T, and L series are given below.

3.2.1 X Series Blades

In this experimental effort, J79 blades were fabricated in three material design types. All blades contained 0.0142 mm (0.0056-inch) diameter boron filament aligned primarily at ±15°. (Figure 6 shows ply details.) The three designs were:

1. Design A, a matrix entirely of 1100 Al.

2. Design B, a bimetal matrix that uses an all-1100 Al matrix in the outer 50% span and an ATAC structure in the lower 50% span of the root.

3. Design C, an all-ATAC (alternating aluminum foils of 1100 and 2024) stratification structure.

The X series blades fabricated by GE's M&PTL Laboratory, together with the blades fabricated by TRW, Inc., were transferred to the Air Force program for testing. Evaluation in a screening test was accomplished May 22, 1977.

A total of 11 blades of the experimental X series were consolidated; the first two were process development blades. In this series of blades, a number of ply changes and die modifications were required. The latter were employed in conjunction with ESP (Evaluating Surface Pressure), a recently developed technique (Reference 4).

The ESP technique is a rapid, low-cost method of detecting surface pressures by means of an intermediate wire-mesh layer. The technique requires that a calibration curve be established first to provide information about thickness changes in compressing aluminum wire cloth at known pressures. Next, the aluminum wire cloth is placed between the pressed part and the faying surfaces of the dies. By measuring variations in the wire screen thickness, and by consulting the calibration curve, a pressure gradient can be determined between the die and the part.

In the first step of blade fabrication, the 0.142 mm (0.0056 inch) diameter filament was drum wound at a spacing of 0.165 mm (0.0065 inch). This resulted in a monotape 0.196 mm (0.0077 inch) thick when pressed. Both the base and the aluminum cover sheet (1100 or 2024) were 0.051 mm (0.002 inch) thick. The technique and procedures for tape manufacture have been described in Subsections 2.2 through 2.4. In this program, three types of bonded monotape (BMT) sheets were formed. In one instance, the 1100 Al covered both sides to form the all-1100 Al sheets. The second type consisted of 1100 Al on one surface and 2024 Al on the other to form the ATAC sheets. The third type consisted of all 1100 Al on one surface, the other surface covered half with 1100 Al and half with 2024 Al. This is a patented process (Reference 5). A schematic for preparation of the bonded monotapes was shown in Figure 5, located in Subsection 2.2.5 (Ply Generation and Assembly) of the fabrication process section. After the tapes were pressed for 10 minutes at 160° C, 24.1 MPa (860° F, 3.5 ksi), the PROS cover sheets were removed and the BMT's given a chemical surface treatment, Stillman/Farmer No. 9, consisting of an alkaline cleaning operation, an acid deoxidizer step, and finally a fixant operation. Details of the treatment can be found in Table VI, located in Subsection 2.2.4.

Routing sheets, an example of which is shown in Figure 19 for Blade X9, were used in the fabrication of all blades. The B/Al plies were cut from the BMT's with a steel-rule knife tool as described in Subsection 2.2.5. A total of 32 B/Al plies was cut for each blade. All cut plies were carefully inspected to assure a well-bonded condition.

The stainless steel mesh and Al plies were generated by sandwiching the wire mesh between 2024 Al sheets. Then, they were roll-bonded between Mylar film, as discussed in Subsection 2.2.4. After rolling, the Mylar layer was removed, and all tapes were visually inspected. The tapes for both the root plies and the outer layer plies measured 89 mm by 292 mm (3-1/2 inches by 11-1/2 inches).

ROUTING SHEET

Part Name	Serial No.	Page
B/Al Blade 1J79 Compr. Rotor, Stg I	CJ79-556(2/1R-1T)-X9	1 of 1

Part Number		Quality Level	Routing Sheet
4013179-420	CJ79-556(2/1R-1T)-X9		Issue Date—— Rev.No. ——

OPER NO	OPERATION DESCRIPTION	OPERATOR BADGE NO	COMPL DATE	OPER NO	OPERATION DESCRIPTION	OPERATOR BADGE NO	COMPL DATE
10	Accumulate Materials	48868 ACL	12/14/76				
1100 2024	~~GRB~~ BMT Tape No. BMT 1/(12)6-12-1 THRU-8 BMT 1/26-10-10 & -11 Mesh Lot No. 1.5-37 & 2.0-11 Al Foil Q/A No. 0124-1 Al Foil Q/A No. 0086 & 0101 Matrix Box No. K						
20	Punch out ply patterns	48868 ACL	12/14/76				
30	Inspect ply patterns	48868 ACL	12/14/76				
40	Assemble ply patterns	48868 ACL	12/14/76				
50	Vacuum hot pressing	15980	12/17/76				
60	Clean and bench	15980	12/18/76				
70	Visual Inspection	15980	12/18/76				
80	Clear paperwork	15980	12/13/76				

Figure 19. Typical Routing Sheet for Fabrication of CJ79 B/Al Blades.

The SS mesh/Al plies were cut from the rolled tapes, again using the steel-rule knives which were formed from a set of master plies. These punched-out SS mesh/Al plies were carefully inspected to assure that they were well-bonded. Figure 9 in Subsection 2.2.5 shows the rolled tape, the steel-rule die board, the as-cut mesh, and the completed plies. Each blade required a total of 154 SS mesh/Al or Al ply inserts to form the root region. After being cut, the plies were identified on routing tags and stored.

All of the SS mesh/Al, B/Al, and Al plies in preparation for blade consolidation were laid out on an assembly check board similar to the one that was shown in Figure 10. A photograph was then taken of each blade ply assembly. By using this procedure, a permanent record was kept of the plies incorporated into all blades. In addition to these steps, a 0.127 mm(0.005-inch) T50-coated sacrifical sheet was placed on the outer layers of both the concave and the convex surfaces to provide a uniform pressure during the bond cycle. Figure 20 is a process operation sheet for the type and stacking sequence of any one blade - in this case, Serial Number X9. A typical ply assembly, arranged in stacking sequence, is shown in Figure 21.

All the plies were stacked in the shuttle box, along with the extractable dovetail ply which contains filaments from the same lot as used for the blade. The shuttle box served as an assembly container, a press location fixture, and a matrix box for machining consolidated blades. The assembly of the plies in the shuttle box, Figures 11 and 12, is detailed in Subsections 2.2.5 and 2.2.6. This shuttle box concept allows for the rapid bond cycle (RBC) in which the ply patterns can be sequentially stacked and placed into the press preheated to 371° C (700° F). The ply assembly contained in the matrix box was inserted into the die; the top die was brought into contact with the plies, and the vacuum chamber was closed and evacuated. This operation took about 15 minutes. The die, the plies, and the shuttle box were rapidly heated to the desired temperature of 493° C (920° F) for a total time of 35 minutes. The pressures employed were 41.4 MPa (6 ksi) for the ATAC blades, 48.3 MPa (7 ksi) for the bimetal blades, and 55.2 MPa (8 ksi) for the all-1100 Al blades. Following the press cycle, the power was turned off and the consolidated part cooled in a vacuum under pressure. Although this slow-cooling method was used in this progam, processing studies show that by using argon-cooled fans it is possible to perform the entire bond cycle in about an hour. A typical process data sheet for the RBC consolidation, containing all data regarding time, die temperature, chamber vacuum, applied pressure, and press travel, can be seen in Figure 22.

After cooling, the blade was removed from the press. Then a spatula and pliers were used to peel the sacrificial sheets from each side of the formed blade. The extra tool root ply was also removed from the blade-root region and the matrix dissolved away in a 20% solution of NaOH. The extracted boron filaments were then tensile tested and their strength compared with those measured before pressing. These results, from before and after pressing, are shown in Table IX. They indicated that there was no significant filament degradation. After tensile testing of the boron filaments, the molded blades were lightly grit-blasted with 150-grit alumina to remove the residual release agent transferred from the outer sacrificial sheets.

MPTL BORON/ALUMINUM

PART *J79 BLADE - STG. 1* | PART No. *CJ79-556(2/1R-1T)-X9* | SHEET *1* OF *5*

DRAWING No. *4013179-422* | PROJECT *J79* | REFERENCE *4013179-424*

OPERATION DESCRIPTION: *BMT # 1/(12)6-12-1 THRU -8 & # 1/(12)6-10-10 & -11*

TENSILE SPECIMEN - BMT # 1/(12)6-12-5

ASSEMBLY OF PLY PATTERNS

OPER. No.	STEP		PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	TECHNICIAN & DATE
		✓	OUTER SACRIFICIAL		.0015" AL (T-50 COATED)	2024	ACL
							48868
		✓	2-A	INSERT SIZE	.005" AL	2024	12/14/76
		✓	1-A	INSERT SIZE	BMT 90°		
		✓	3-A	INSERT SIZE	.005" AL (T-50 COATED)	2024	
		✓	4-A & 5-A	INSERT SIZE	.005" AL	2024	
		✓	6-A THRU 26-A	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	26-A-AL	INSERT SIZE	.005" AL	2024	
		✓	27-A THRU 38-A	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	A	OUTER PLY	2.0 MESH TAPE	2024	
		✓	1	BMT	+15°	BI METAL	
		✓	2	BMT	-15°	BI METAL	
		✓	3	BMT	0°	BI METAL	
			NOTE: BORON + DIRECTION = FROM L.E. BASE TO T.E. TIP				

Figure 20. Process Operation Sheet for Stacking of CJ79 Plies.

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 2 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS				
			PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	4	BMT	+15°	BiMetal	
		✓	5	BMT	-15°	BiMetal	
		✓	6	BMT	+15°	BiMetal	
		✓	7	BMT	-15°	BiMetal	
		✓	8	BMT	+15°	BiMetal	
		✓	39-8	Insert Size	2.0 Mesh Tape	2024	
		✓	40-8 thru 52-8	Insert Size	1.5 Mesh Tape	2024	
		✓	52-8-Al	Insert Size	.010" Al	2024	
		✓	53-8 thru 64-8	Insert Size	1.5 Mesh Tape	2024	
		✓	64-8-Al	Insert Size	.010" Al	2024	
		✓	9	BMT	0°	ATAC	
		✓	10	BMT	0°	ATAC	
		✓	11	BMT	0°	ATAC	

Figure 20. Process Operation Sheet for Stacking of CJ79 Plies (Continued).

PART	PART No.	SHEET 3 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	12	BMT	0°	ATAC	
		✓	13	BMT	0°	ATAC	
		✓	14	BMT	0°	ATAC	
		✓	15	BMT	0°	ATAC	
		✓	16	BMT	0°	ATAC	
		✓	65-16	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	66-16 THRU 77-16	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	77-16-AL	FULL PLY	.003" AL (S/F9 TREATED)	1100	
		✓	78-16 THRU 89-16	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	90-16	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	17	BMT	0°	ATAC	
		✓	18	BMT	0°	ATAC	
		✓	19	BMT	0°	ATAC	

Figure 20. Process Operation Sheet for Stacking of CJ79 Plies (Continued).

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 4 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	20	BMT	0°	ATAC	
		✓	21	BMT	0°	ATAC	
		✓	22	BMT	0°	ATAC	
		✓	23	BMT	0°	ATAC	
		✓	24	BMT	0°	ATAC	
		✓	24-AL	INSERT SIZE	.010" AL	2024	
		✓	91-24 THRU 103-24	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	103-24-AL	INSERT SIZE	.010" AL	2024	
		✓	104-24 THRU 115-24	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	116-24	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	25	BMT	+15°	Bi METAL	
		✓	26	BMT	-15°	Bi METAL	
		✓	27	BMT	+15°	Bi METAL	

Figure 20. Process Operation Sheet for Stacking of CJ79 Plies (Continued).

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 5 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION — ASSEMBLY OF PLY PATTERNS: PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	TECHNICIAN & DATE
		✓	28	BMT	-15°	B, METAL	
		–	29	BMT	+15°	B, METAL	
		✓	30	BMT	0°	B, METAL	
		✓	31	BMT	-15°	B, METAL	
		✓	32	BMT	+15°	B, METAL	
		✓	B	OUTER PLY	2.0 MESH TAPE	2024	
		✓	117-B THRU 129-B	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	129-B-AL	INSERT SIZE	.005" AL	2024	
		✓	130-B THRU 149-B	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	150-B THRU 154-B	INSERT SIZE	.005" AL	2024	
		✓	OUTER SACRIFICIAL	.005" AL (T-50 COATED)		2024	

Figure 20. Process Operation Sheet for Stacking of CJ79 Plies (Concluded).

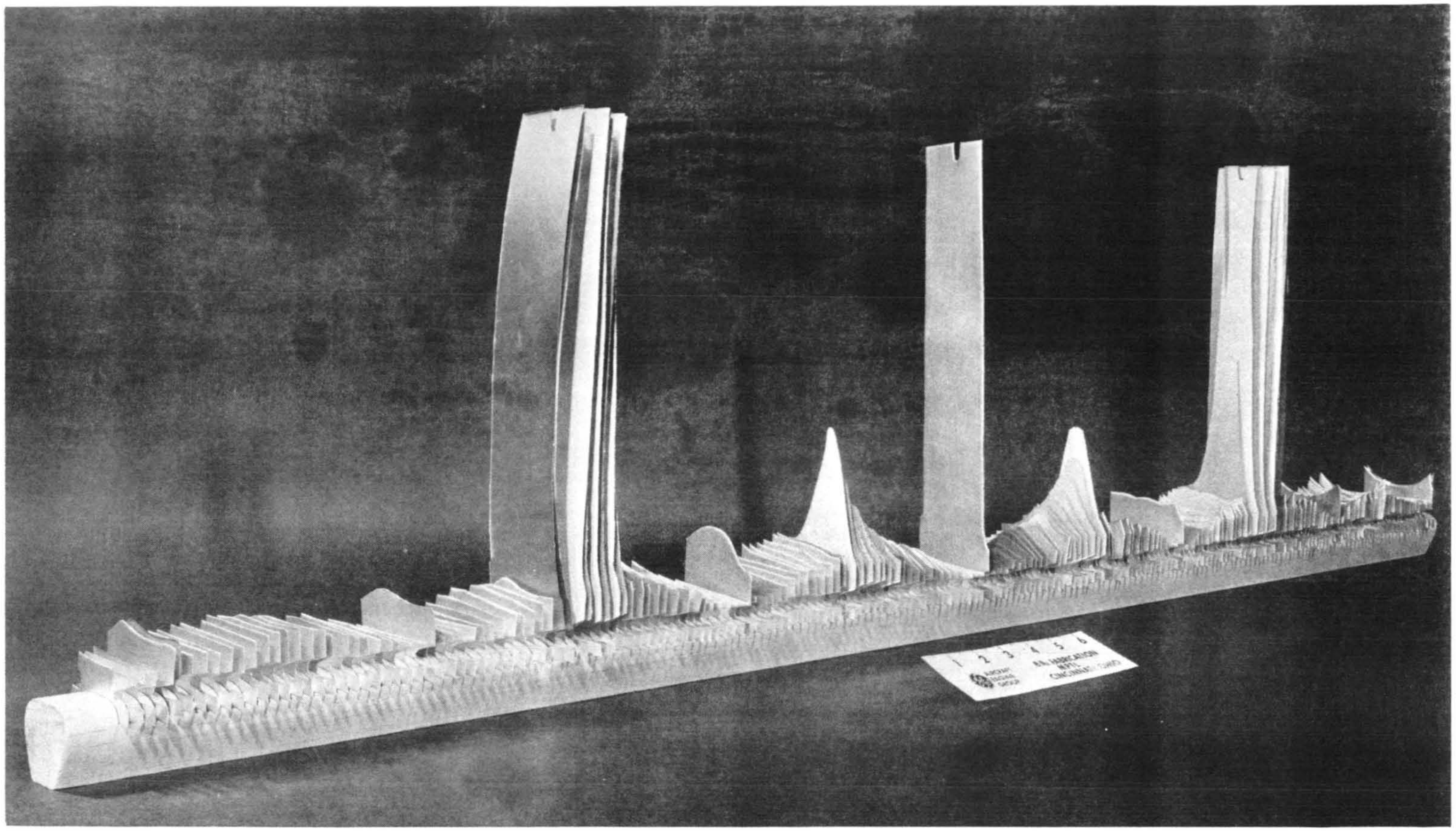


Figure 21. Assembly of B/Al and SS Mesh/Al Plies Arranged in Stacking Sequence.

I-J-79 PROGRAM
PROCESS DATA SHEET

CJ79-556(2/1R-17)-X9

Oper No.	Operation	Part Name								Part No.		Serial No.
50	Vacuum Hot Press	B/Al Blade IJ79 Compressor Rotor, Stage 1								4013179-420		-X9
Time	Event	Lower die temp °F			Upper die temp °F			Chamber		Load	Dial Gage Reading	Operator Badge No.
		TC	TC	TC	TC	TC	TC	Vac.	Pres.			
0830	DIE HEAT UP	650	690	690	650	650	650					
	VACUUM OFF, FILL CHAMBER WITH ARGON, OPEN CHAMBER,											T. JONES
	MATRIX BOX INSTALLED IN DIE, CHAMBER CLOSED AND PUMPED DOWN.											#15980
0845	DIE HEAT UP	605	680	680	660	610	605	3.2×10^{-4}			.094	
1000	50,000 LB. LOAD	850	800	800	855	805	805	3.2×10^{-4}			.534	
	100,000 LB. LOAD										.545	
	150,000 LB. LOAD										.553	
1005	198,400 LB. LOAD										.561	
	(FULL LOAD, 7KSI)											
1025	START TIME @ TEMP.	918	922	922	922	922	920	2.2×10^{-4}			.562	
1030		920	925	925	925	925	922	2.0×10^{-4}			.562	
1035		925	930	930	930	930	925	2.2×10^{-4}			.564	
1040		925	930	930	930	930	930	2.2×10^{-4}			.566	
1045		925	930	930	925	930	930	2.2×10^{-4}			.566	
1050		922	930	930	922	930	925	2.2×10^{-4}			.567	
1055		920	930	930	920	925	922	2.2×10^{-4}			.568	
1100	END OF CYCLE - 35 MIN.	915	925	925	915	920	918	2.2×10^{-4}			.568	
1101	COOL DOWN UNDER VACUUM AND FULL LOAD											

Press No. V-825 Die Set No. 2 Matrix Box No. K Date Pressed 12-15-76 Date Unloaded 12-16-76

Comments: PREHEAT DIE TO 700°F, FILL CHAMBER WITH ARGON AND OPEN, LOAD MATRIX BOX IN DIE AND CLOSE CHAMBER AND PUMP DOWN. QUICK HEAT UP CYCLE IN VACUUM, PRESS CYCLE 920°F $\pm 10^{\circ}$ / 35 MIN. / 7 KSI. APPLY FULL LOAD @ 850°F AND VACUUM IN 10^{-4} RANGE, COOL DOWN UNDER VACUUM AND FULL LOAD.

Figure 22. Typical Process Data Sheet for RBC Consolidation of CJ79 Blades.

Table IX. Boron Filament Tensile Strengths Before and After Pressing - GE Fabricated X Series J79 B/Al Blades.

Design	Blade Serial Number	Type	Winding Number[1]	Average Strength Before Pressing[2]		Average Strength After Pressing[3]	
				MPa	(ksi)	MPa	(ksi)
C	CJ79-5562/1-X3	ATAC	B16-17	3316	(481.0)	3383	(490.7)
A	CJ79-5561-X4	A11-1100	B16-24	3685	(534.5)	3506	(508.5)
A	CJ79-5561-X5	A11-1100	B16-22	3607	(523.2)	3627	(526.1)
C	CJ79-5562/1-X6	ATAC	B16-15	3303	(479.0)	3458	(501.5)
C	CJ79-5562/1-X7	ATAC	B16-12	3573	(518.2)	3361	(487.4)
A	CJ79-5561-X8	A11-1100	B16-29	3648	(529.1)	3426	(496.9)
B	CJ79-556(2/1R-1T)-X9	Bimetal	B16-32	3200	(464.1)	3232	(468.8)
B	CJ79-556(2/1R-1T)-X10	Bimetal	B16-30	3619	(539.4)	3661	(530.9)
B	CJ79-556(2/1R-1T)-X11	Bimetal	B16-34	3554	(515.4)	3747	(543.5)

(1) Refer back to Table V for additional information on filaments.

(2) Based on an average of 5 specimens taken prior to winding or pressing the boron filaments into the blades.

(3) Based on an average of 5 specimens taken after pressing the boron filaments into each blade.

Before they were delivered to Air Force Program F33657-76-C-0608, the blades were nondestructively examined by through-transmission ultrasonic C-scans. This inspection technique employs a master-blade-contour follower to allow complete airfoil scanning. Details on this ultrasonic inspection procedure are available in Reference 3. When evaluating the scanned blades, certain signs were noted that seemed to indicate surface defects. To verify this, three previously scanned blades were polished by a surface-abrasion operation. Figure 23 shows a C-scan from before the surface cleanup; Figure 24 shows a C-scan from after the surface cleanup. Because the latter C-scan revealed fewer signs of defects, some of the indicated defects were concluded to be related to surface contour. All nine experimental blades were similarly benched and are shown in Figure 25 as they appeared prior to machining.

3.2.2 S Series Blades

In the effort to evaluate the capacity of the B/Al blade for (or "sensitivity" to) bird strikes, two types of designs were fabricated:

1. Design B, bimetal design, designated Design 1 during testing.
2. Design F, modified bimetal design, designated Design 2 during testing.

All blades of both designs were pressed for 35 minutes at nominal conditions of 493° C and 55.2 MPa (920° F and 7 ksi).

Design B was of the same construction as the bimetal blade configuration of the X series successfully tested previously in May 1977. All details of blade processing have been described under Subsection 3.2.1 (X Series blades) and in the fabrication process section. The logic in using Design B in the S series was that Design B would not change the blade characteristics that had successfully met minimum bird-impact requirements. The only difference would be that the center B/Al ply would be formed from a steel-rule die instead of by hand cutting.

Design F was to be of the same basic bimetal blade construction but with provisions for a square filament array. The bimetal full-length plies were composed of 0.142 mm (0.0056 inch) diameter boron, as in Design B, with a matrix of 1100 Al in the upper 50% span and of ATAC in the lower 50% span. To provide for a square filament array with a ply thickness of 0.183 mm (0.0072 inch), the filaments were wound at a nominal spacing of 0.183 mm (0.0072 inch). Panels from BMT sheets were fabricated in this manner and metallographically observed to have a spacing of about 0.188 mm (0.0074 inch) with a consolidated ply thickness of 0.185 mm (0.0073 inch). A single sheet of 1100 Al foil with a Stillman/Farmer No. 9 surface treatment formed the center ply. This center ply was 0.127 mm (0.005 inch) thick in Design F; it was 0.076 mm (0.003 inch) thick in Design B. The outer surface ply consisted of the 316-type stainless steel wire mesh

Figure 23. Ultrasonic C-Scan - Before Surface Cleanup.

Figure 24. Ultrasonic C-Scan - After Surface Cleanup.

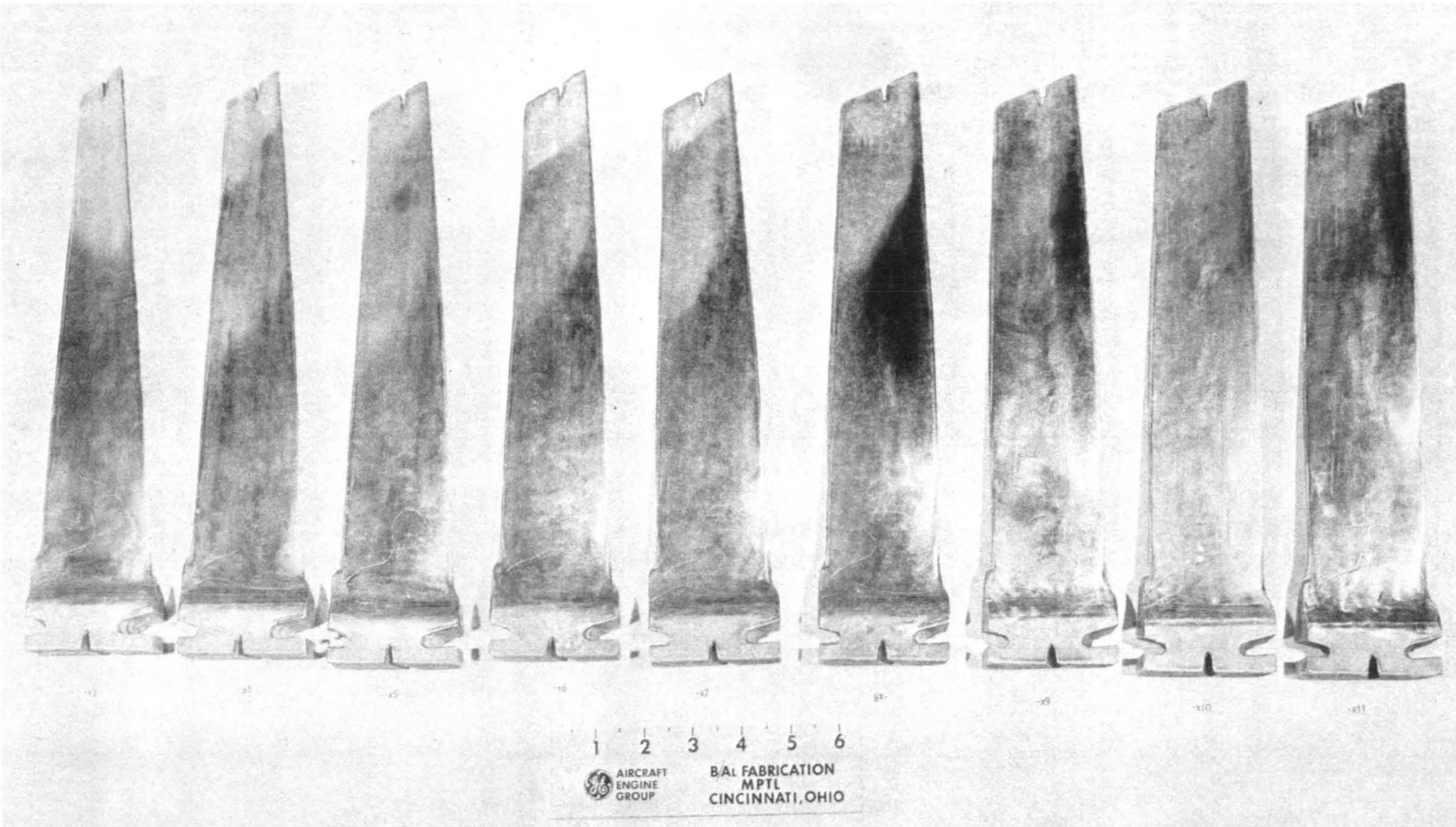


Figure 25. The Nine Experimental (X Series) Blades Prior to Machining.

sandwich between two 100 Al foils. The inner foil layer was of 0.051 mm (0.002 inch) 1100 Al; the outer layer, 0.157 mm (0.005 inch) 1100 Al. The 1100 Al in the outer ply represented a change from the Design B blades in an effort to incorporate a more ductile outer layer and thereby offer a more crack-resistant surface.

Since the B/Al ply thickness of Design F blades was only 0.183 mm (0.0072 inch) compared to 0.196 mm (0.0077 inch) in Design B, four additional plies, making 36, were needed to fill the die cavity of the blade. Figure 26 is comprised of the process operation sheets for the type and stacking sequence of a typical Design F blade.

A total of eight Design B blades was fabricated. The first two of these were trial blades used to derive an optimum fill with the steel-rule die patterns. The last six were transferred to the Air Force program. A total of 10 Design F blades was fabricated. Since this design was a modification of the bimetal Design B and involved new ply patterns, the first five of these blades were trial blades used to derive the optimum fill. The latter five were transferred to the Air Force program. Boron filament strengths of these sensitivity blades, measured both before and after pressing, do not reveal any significant change arising from the press cycle. This stability is shown in the tabulation of filament strengths, Table X.

Before being transferred to the Air Force program, the 11 sensitivity blades were nondestructively examined by through-transmission ultrasonic C-scans, using the procedure described for the X series blades. From these C-scans, the sensitivity blades were judged to be of high quality.

3.2.3 T and L Series Blades

As a consequence of bird-impact sensitivity testing in December 1977, the Design B blades were selected for further evaluation in a full-stage rig test in the Air Force program. All blades were pressed for 35 minutes at nominal conditions of 493° C and 55.2 MPa (920° F and 7 ksi).

The filament strengths for some of the blades are shown in Table XI. Before being transferred to the Air Force program, these test blades were nondestructively evaluated (NDE) by through-transmission ultrasonic C-scans, using the procedure described for the X series blades.

The evaluation of the T series blade C-scans showed that all the blades had indications that could be interpreted as disbonds and/or surface roughness. The indications were similar to those found on the X and S series blades and were within the NDE limits defined on the blade drawing. However, the lack of correlation between blade NDE data and foreign-object-damage (FOD) resistance in previous blade tests indicated that NDE was not effective in identification of blade FOD performance. Therefore, further evaluation of blade quality was necessary to attempt to identify the blades most acceptable for FOD testing. A correlation was identified between blade FOD resistance

MPTL BORON/ALUMINUM DESIGN II - 7.2 PLY THK.

PART J79 BLADE - STG. 1	PART No. CJ79-556(2/1R-1T)-251	SHEET 1 OF 5
DRAWING No. 4013179-989	PROJECT J79	REFERENCE 4013179-986

OPER. No.	STEP		OPERATION DESCRIPTION BMT # 20 / TENSILE SPEC. BMT # 20-20	TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No. SIZE ORIENTATION MATERIAL	
		✓	OUTER SACRIFICIAL .005" AL (T-50 COATED) 2024	[illegible]
				48868
		✓	2-A INSERT SIZE .005" AL 2024	8/11/77
		✓	1-A INSERT SIZE BMT 90°	
		✓	3-A INSERT SIZE .005" AL (T-50 COATED) 2024	
		✓	4-A & 5-A INSERT SIZE .005" AL 2024	
		✓	6-A THRU 38-A INSERT SIZE 1.5 MESH TAPE 2024	
		✓	A OUTER PLY OUTER/INNER 5.0/2.0 MESH TAPE 1100	
		✓	AA-AL INSERT SIZE .005" AL 2024	
		✓	1 BMT -15° BIMETAL	
		✓	2 BMT +15° BIMETAL	
		✓	3 BMT -15° BIMETAL	
		✓	4 BMT +15° BIMETAL	
			NOTE: BORON + DIRECTION = FROM L.E. BASE TO T.E. TIP	

Figure 26. Process Operation Sheets for Type and Sequence in Stacking Design of Two-Blade Plies.

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 2 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	5	BMT	−15°	B/METAL	
		✓	6	BMT	+15°	B/METAL	
		✓	7	BMT	−15°	B/METAL	
		✓	8	BMT	+15°	B/METAL	
		✓	9	BMT	−15°	ATAC	
		✓	39-9	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	40-9 THRU 52-9	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	52-9-AL	INSERT SIZE	.010" AL	2024	
		✓	53-9 THRU 64-9	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	64-9-AL	INSERT SIZE	.010" AL	2024	
		✓	10	BMT	+15°	ATAC	
		✓	11	BMT	0°	ATAC	
		✓	12	BMT	0°	ATAC	

Figure 26. Process Operation Sheets for Type and Sequence in Stacking Design of Two-Blade Plies (Continued).

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 3 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	13	BMT	0°	ATAC	
		✓	14	BMT	0°	ATAC	
		✓	15	BMT	0°	ATAC	
		✓	16	BMT	0°	ATAC	
		✓	17	BMT	0°	ATAC	
		✓	18	BMT	0°	ATAC	
		✓	65-18	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	66-18 THRU 77-18	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	77-18-AL	FULL PLY	.005" AL (SIF 9 TREATED)	1100	
		✓	78-18 THRU 89-18	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	90-18	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	19	BMT	0°	ATAC	
		✓	20	BMT	0°	ATAC	

Figure 26. Process Operation Sheets for Type and Sequence in Stacking Design of Two-Blade Plies (Continued).

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 4 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	21	BMT	0°	ATAC	
		✓	22	BMT	0°	ATAC	
		✓	23	BMT	0°	ATAC	
		✓	24	BMT	0°	ATAC	
		✓	25	BMT	0°	ATAC	
		✓	26	BMT	0°	ATAC	
		✓	27	BMT	+15°	ATAC	
		✓	27-AL	INSERT SIZE	.010" AL	2024	
		✓	91-27 THRU 103-27	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	103-27-AL	INSERT SIZE	.010" AL	2024	
		✓	104-27 THRU 115-27	INSERT SIZE	1.5 MESH TAPE	2024	
		✓	116-27	INSERT SIZE	2.0 MESH TAPE	2024	
		✓	28	BMT	-15°	ATAC	

Figure 26. Process Operation Sheets for Type and Sequence in Stacking Design of Two-Blade Plies (Continued).

MPTL BORON/ALUMINUM

PART	PART No.	SHEET 5 OF 5
DRAWING No.	PROJECT	REFERENCE

OPER. No.	STEP		OPERATION DESCRIPTION				TECHNICIAN & DATE
			ASSEMBLY OF PLY PATTERNS PLY PATTERN No.	SIZE	ORIENTATION	MATERIAL	
		✓	29	BMT	+15°	Bi Metal	
		✓	30	BMT	-15°	Bi Metal	
		✓	31	BMT	+15°	Bi Metal	
		✓	32	BMT	-15°	Bi Metal	
		✓	33	BMT	+15°	Bi Metal	
		✓	34	BMT	-15°	Bi Metal	
		✓	35	BMT	+15°	Bi Metal	
		✓	36	BMT	-15°	Bi Metal	
		✓	BB-AL	Insert Size	.005" AL	2024	
		✓	B	Outer Ply	Inner/Outer 2.0/5.0 Mesh Tape	1100	
		✓	117-B thru 149-B	Insert Size	1.5 Mesh Tape	2024	
		✓	150-B thru 154-B	Insert Size	.005" AL	2024	
		✓	Outer Sacrificial	.005" AL (T-50 Coated)		2024	

Figure 26. Process Operation Sheets for Type and Sequence in Stacking Design of Two-Blade Plies (Concluded).

Table X. Boron Filament Tensile Strengths Before and After Pressing - GE Fabricated S Series J79 B/Al Blades.

Design	Blade Serial Number	Type	Winding[(1)] Number	Average[(2)] Strength Before Pressing MPa	(ksi)	Average[(3)] Strength After Pressing MPa	(ksi)
B	CJ79-556(2/R-1T)-1S3	Bimetal	B16-35	3816	(552.8)	3318	(481.2)
B	CJ79-556(2/R-1T)-1S4	Bimetal	C16(6.5)-16	3268	(474.0)	3217	(466.6)
B	CJ79-556(2/R-1T)-1S5	Bimetal	C16(6.5)-10	3279	(475.5)	3430	(497.4)
B	CJ79-556(2/R-1T)-1S6	Bimetal	C16(6.5)-11	3190	(462.6)	3299	(478.4)
B	CJ79-556(2/R-1T)-1S7	Bimetal	C16(6.5)-6	3134	(454.6)	3151	(457.0)
B	CJ79-556(2/R-1T)-1S8	Bimetal	C16(6.5)-8	3370	(488.7)	3324	(482.1)
F	CJ79-556(2/R-1T)-2S1	Bimetal	C16(7.2)-21	3490	(506.2)	3450	(500.3)
F	CJ79-556(2/R-1T)-2S5	Bimetal	C16(7.2)-38	3337	(484.0)	3174	(460.4)
F	CJ79-556(2/R-1T)-2S7	Bimetal	C16(7.2)-36	3634	(527.0)	3350	(485.8)
F	CJ79-556(2/R-1T)-2S9	Bimetal	C16(7.2)-46	3413	(495.0)	3671	(532.4)
F	CJ79-556(2/R-1T)-2S10	Bimetal	C16(7.2)-49	3323	(482.0)	3403	(493.5)

(1) Refer back to Table V for additional information on filaments.

(2) Based on average of 5 specimens taken prior to winding or pressing the boron filaments.

(3) Based on an average of 5 specimens taken after the pressing of each blade.

Table XI. Boron Filament Tensile Strengths Before and After Pressing - GE Fabricated T Series J79 B/Al Blades.

Design	Blade Serial Number	Type	Winding Number (1)	Average Strength Before Pressing MPa (ksi) (2)	Average Strength After Pressing MPa (ksi) (3)
B	CJ79-556(2R-1T)-1T1	Bimetal	C16(6.5)-66	3448 (500)	3123 (453)
B	-1T3	Bimetal	C16(6.5)-64	3282 (476)	3510 (509)
B	-1T4	Bimetal	C16(6.5)-90	3208 (465)	3077 (446)
B	-1T5	Bimetal	C16(6.5)-99	3448 (500)	3222 (467)
B	-1T6	Bimetal	C16(6.5)-94	3249 (471)	2773 (402)
B	-1T13	Bimetal	C16(6.5)-137	3167 (459)	3105 (450)
B	-1T15	Bimetal	C16(6.5)-134	3636 (527)	3082 (447)
B	-1T17	Bimetal	C16(6.5)-113	3429 (497)	2836 (411)
B	-1T18	Bimetal	C16(6.5)-128	3319 (481)	2767 (401)
B	-1T19	Bimetal	C16(6.5)-127	3236 (469)	2801 (406)
B	-1T26	Bimetal	C16(6.5)-148	3760 (545)	2905 (421)
B	-1T32	Bimetal	C16(6.5)-155	4105 (595	3077 (446)

(1) Refer back to Table V for additional information on filament.

(2) Based on an average of 5 specimens taken prior to winding or pressing the boron filaments.

(3) Based on an average of 5 specimens taken after the pressing of each blade.

and the area of surface roughness of the sacrificial, unreinforced-aluminum plies included at the outermost surface of the ply stock during blade pressing. The FOD resistance parameters used in the correlation were changes in blade natural frequencies and blade postimpact delamination area. An increase in the area of surface roughness of the sacrifical sheet of blades before FOD test was accompanied by an increase in both the blade frequency change and the area of delamination after bird impact. This correlation was used to select a set of 21 blades for the planned full-stage whirligig impact test. Fifteen of the twenty-one blades selected had an equivalent area or less area of surface roughness than did the X and S series blades which previously underwent single-blade FOD testing.

Incomplete die closure can cause bonding problems as indicated in the fabrication of blades termed the L series. Ultrasonic C-scan data for the blades indicated that tip bonding was inadequate. Investigation revealed that a die shift was causing the two die halves to mate improperly, preventing complete die closure. The problem was overcome by shimming one die half to permit full die closure. In view of the problems encountered and cited above, further diagnostic work and correction to the die alignment will be necessary if additional blade fabrication is to be undertaken.

4.0 CONCLUSIONS AND RECOMMENDATION

With the program completed, the following conclusions can be drawn:

1. The fabrication process developed prior to this NASA contract (Reference Program F33615-71-C-1230, "Boron/Aluminum Compressor Blades") was used successfully, requiring little additional development effort.

2. The die used to produce these blades is no longer suitable for a production run. If more than a few blades must be pressed, further investigation will be necessary to diagnose the cause of the existing die misalignment and fix it.

3. All blades necessary for the Air Force program, F33657-76-C-0608, have been delivered.

Before an extensive production run of blades is undertaken, the pressing die, P/N 4013179-108, should be modified to eliminate the misalignment that currently exists.

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